BOTANY

Specially written to meet the requirements of Teachers' D, Matriculation, Public Service Entrance, Intermediate and Pharmacy A Examinations.

BY

F. NEVE, M.A., LL.B., B.Sc.

Christchurch, Wellington, and Dunedin, N.Z.
Melbourne and London

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Botany.

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T. F. Cheeseman Esq.
(with the author's compliments)

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F. NEVE, M.A., LL.B., B.Sc.

(Head of the Department of Natural Science in the Seddon Memorial Technical College, Auckland.)

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PREFACE.

Recent changes of syllabus in Teachers' D, Public Service Entrance and similar examinations have made it impossible for candidates to sit for Botany and other science subjects without doing a considerable amount of practical work. To supply directions for such work, and at the same time to cover fully the whole Botany course prescribed for each of the above examinations, are the main objects of this book. English text-books, designed to meet English needs, and dealing almost exclusively with English plants, are unsuited to the requirements of New Zealand students; while such New Zealand text-books as deal with the subject treat almost exclusively of Morphology and Classification, and thus leave practically untouched the important branches of Ecology and Physiology, so that the student is left without guidance in such matters as the "Struggle for Existence," "Adaptation to Surroundings," "Plant Societies," "Germination," and "Nutrition." There are, of course, admirable works, like those of Dr. Cockayne, which deal with one or more branches of New Zealand Botany; but these are not written nor are they intended for school purposes. The author, therefore, believes that by bringing together and correlating these different matters his book will supply a real want.

In selecting plant types, care has been taken to exclude those that are difficult of access; while, in the matter of experiments, only those have been described, which, after frequent repetition, have been found capable of producing obvious results without the use of elaborate apparatus or the need for specially skilful manipulation.

The student should realize at the outset that Botany is pre-eminently a subject demanding, in all its branches, personal investigation of things, not words. Merely to read the description of an experiment is a proceeding barren of useful result, but to carry it out with one's own hands, and thus directly to verify or discover, is to open a door of knowledge that can never again be shut.

In any satisfactory Botany course field-work is of the first importance; for it is by the study of plants when growing under natural conditions that the student acquires a living interest, and at the same time obtains that broad and comprehensive view, which alone can illuminate the investigation of detail that must be carried out in the laboratory. In short, field-work vitalizes the whole subject.

In conclusion, the writer wishes to thank all those who have been so ready to give assistance—Dr. Cockayne and Mr. Lancaster for useful photographs and suggestions, and Mr. Ash, Chief Art Instructor of the Seddon Memorial Technical College, for his invaluable help in connection with the illustrations.

DEFINITION OF BOTANY IN PUBLIC EXAMINATIONS.

SYLLABUS FOR TEACHERS' D CERTIFICATE.

The candidate will be required to show that he has acquired his knowledge of the following topics by observation, investigation and experiment:—

The organs of flowering plants, their arrangement and principal modifications; their functions, so far as they can be ascertained by observation and simple experiments.

The general structure, distribution and arrangement of plant-tissues, so far as they can be studied with the aid of a good hand lens. The structure of fruits; the various kinds of fruits.

The main phenomena of the life-history (excluding microscopic processes) of common flowering plants; germination; establishment and growth; comparison of the different types of germination; the mechanism of pollination; fruit and seed dispersal.

Structure of garden soil; different types of soil and their air and water contents; rough methods of mechanical analysis of soils.

Elementary knowledge of the chemical constituents of plants and the sources from which the plant obtains them.

Simple qualitative and quantitative experiments illustrating the nutrition of plants, the conduction of water and food substances in the plant, storage of reserve material, respiration, transpiration, irritability.

The struggle for existence; adaptation of plants to their surroundings and to cold and drought, protection against animals; comparison of creeping plants, rosette-forming plants, shrubs, trees, and climbing-plants; the shapes of leaves and the causes to which they are due; plant societies.

The identification of common trees at different seasons by means of various parts and organs, such as buds, bark, leaves, etc.

The description and dissection of commonly occurring flowering plants (technical descriptions will not be demanded).

A general knowledge of the following natural orders:—Liliaceæ, Ranunculaceæ, Cruciferæ, Umbelliferæ, Leguminosæ, Myrtaceæ, Rosaceæ, Compositæ, Gramineæ—with a special knowledge of at least one indigenous and one exotic typical member of each order.

The candidate will be required to forward, before the date of examination, a certificate in the prescribed form that he has carried out satisfactorily a course of practical work based on the above syllabus.

PUBLIC SERVICE ENTRANCE.

This syllabus is practically the same as the above, the only real difference being the omission of the section relating to soils. The omission of "The Struggle for Existence," "Irritability," "Shapes of Leaves," and the specified Natural Orders is apparent rather than real, for a study of these topics is necessarily implied in that of the other items enumerated.

MATRICULATION.

For Matriculation, Botany forms only half a subject, being included under the heading of Natural Science.

In Natural Science two papers are set:—

(*a*) A very general paper dealing broadly with Physics and Chemistry.

(*b*) Any one of the following:—

i. Elementary Home Science.
ii. Elementary Hygiene and Physiology.
iii. Elementary Zoology.
iv. Elementary Botany.

The Elementary Botany is practically the same as that for D Certificate, the only important omission being that of the section dealing with garden-soil.

PHARMACY A.

For this examination the syllabus is essentially the same as that for Public Service Entrance, except for the fact that no plant description is demanded.

PRACTICAL WORK.

Teachers' D.—The certificate, a form for which may be obtained from the Education Department, should show that the candidate has taken (1) a course extending over two or more years at a Secondary School, the Secondary Department of a District High School or a Technical High School, or (2) an approved course for teachers arranged by an Education Board. In either case, not less than forty hours must be devoted to individual practical work by the candidates themselves.

Public Service Entrance, Intermediate, etc.—The certificate should show a one year's course at least, as provided at a Secondary School, or in the Secondary Department of a District High School, or in a Technical High School. Of this course not less than thirty hours must be devoted to individual practical work by the candidates themselves.

Matriculation.—Every candidate must forward to the Registrar of the University before the examination a certificate from the principal of his school that he has carried out satisfactorily a course of practical work based on the syllabus, provided that a candidate who is unable to comply with this condition may, with the permission of the Chancellor, submit his note-book of practical work to the principal of some Secondary or Technical School approved by the Chancellor for the purpose.

Pharmacy A.—No certificate required.

CONTENTS.

LIST OF ILLUSTRATIONS.

BOTANY

CHAPTER I.

ORGANS OF FLOWERING PLANTS.

All living things, whether plants or animals, must do work and carry out certain processes in order that they may continue to live and remain healthy and vigorous. Consider for a moment one of the higher animals such as the horse or sheep. It must eat, breathe, digest its food, and carry out a hundred other processes necessary to its welfare. Each part of its body is built to suit exactly the particular kind of work required of it: the lungs do the breathing, the stomach helps in digestion, and the heart pumps the blood to every part of the animal. Such special parts of a living thing which thus do special work, or, in other words, carry out special functions, are called **organs**, and the individual to which they belong is an organism.

Plants no less than animals are organisms, for they too have their organs, each adapted to its particular work. The root obtains food from the soil and the leaf secures food from the air, while the stem forms a highway of communication between the two.

It must not be supposed that every organism has a variety of organs, for the term embraces everything that carries out the functions of life, and thus includes even the lowliest plants and animals. Bacteria, for instance, among plants, and the amœba among animals consist of but a single cell. This cell breathes, gathers

and digests food, indeed, carries out all the functions of the individual, and thus is its one and only organ.

The organs of flowering plants fall naturally into two groups, the vegetative and reproductive. To make a general study of these will be the first step, and for this purpose it will be necessary to select some common plant or plants for examination. Unfortunately there is no suitable native plant readily available in all parts of the Dominion, and we are therefore compelled to fall back on some introduced example to supply the material we need.

Because of its large seed, the fairly typical structure of its stem and leaf, the size and distinctness of the different parts of its flower, the ease with which it germinates and may be raised from seed at any time of the year, and above all because it can everywhere, without difficulty, be obtained in considerable quantities, the broad bean plant is chosen for the purpose.

Vegetative Organs.

The vegetative organs are the organs through which a plant is related to its environment, in other words, through which it makes use of, and has adapted itself to the things and conditions by which it is surrounded. To take a simple example, the root is the organ by which the plant is related to the soil, by means of which it is fixed firmly in position, and through which it absorbs the water and dissolved minerals with which it is in contact. The leaf on the other hand is concerned chiefly with the light and air relation, for it is through the leaf and from the air that the plant receives most of its food, which, utilising the energy of the sunlight, it builds up into the substances required for development and growth. The stem is rather a subsidiary organ carrying raw material from root to leaf and conducting the substances manufactured there to every

part of the plant. Nevertheless, the stem, by spreading out the leaves, is concerned with the light and air relation, while, by displaying the flowers and fruit, it helps to relate the plant to insect and other animal life around it, and thus provides for pollination, and secures the distribution of its seed.

1. **The Root** (Fig. 2) is the organ which relates the plant to the soil. To study the root, dig a trench round a mature bean plant grown in a clear piece of ground, and, by gradually cutting away slices from the inner side of the trench, observe the extent to which the roots explore the soil. It will be found, on nearing the plant, that every cubic inch of earth is penetrated by one, sometimes many root branches.

By growing one plant in a plot of good garden soil, and another in a patch of almost pure sand, it may be observed how a plant adapts itself to its surroundings or responds to environment. Provided there is nothing abnormal in the season, the plant growing in soil will show only ordinary root development in spite of the unusual size and vigour of its leaves and stem; while that growing in the sand, though stunted as to leaves and stem, will produce an enormous mass of branching roots which leave no cranny of the soil untapped. In the one case there was abundant food and moisture to provide for growth even of the strongest shoot, while in the other, to find the materials necessary even for the much smaller stem and leaves, every soil particle and tiny water reservoir had to be put under contribution. This excessive production of roots was therefore a response to adverse conditions, an adaptation to environment.

Now remove several plants from the soil, each in a large block of earth, so that the roots may not be cut or broken. Then wash away the soil, preferably with a hose, place the root ends in a large bowl of

water and examine the different parts in detail. In addition, each student should have his own plant, which may be removed from the soil with a spade and washed under the tap. Such parts as are missing may be examined in the more carefully removed specimen. There is one main root called the tap-root, which goes down deep into the soil and tapers towards the tip. This throws off branches throughout its entire length, and these again produce secondary branches, which in their turn may branch repeatedly. By cutting through the main root just where a branch is given off it may be seen that the branch has burst through from the inside, having its origin in the interior tissues (Fig. 3).

The older parts of the root are hard and woody, but as we approach the ends of the more slender branches we find the tissues soft and tender. The aggregate length of all the root branches is very great, and by measuring a few of these and counting the rest, this may be roughly calculated.

The root system of a maize plant examined by the author in this way, showed, without root hairs, a total of about 350 yards, while it is stated on good authority that the root system of a Spanish vine reached an aggregate length of 15 miles, and that of this length the major part must have been produced at the rate of 1,000 feet per day.

Now examine the ends of the more delicate root branches with a lens. These will be found to be covered almost to their tips with a delicate fur of white root hairs. These hairs are the really active parts of the root which do the work of absorbing the soil-water with its dissolved minerals. It is only close to the root tips that these hairs are found. The extreme tip, however, is devoid of hairs, being covered by the root cap which protects the delicate growing point as

it forces its way through the soil. The root tip must at times exert enormous force, for it penetrates the hardest soils, even the cement-like clays so common in some parts of New Zealand forming no bar to its progress. For fear that the root hairs and root caps may have been broken off or injured in removing the bean plant from the soil, place a number of barley grains and mustard seeds to germinate between layers of moist flannel. These will show abundance of root hairs (Fig. 4) and will exhibit the root-cap distinctly outlined as a conical transparent mass at the extreme tip, behind which may be seen the denser tissue of the growing point.

Nodules. On the roots of the bean will be noted little fleshy swellings forming the well known nodules or tubercles. These are peculiar to plants belonging to the bean family, and their significance will appear later on.

2. **The Stem** (Fig. 1). The objects of the stem are:
   (*a*) To place the leaves in positions in which they can get most air and sunlight.
   (*b*) To display the flowers so that insects may readily see them.
   (*c*) To place the fruit in the positions most suitable for distribution, whether by wind, water, birds or other animals.
   (*d*) To afford a passage from root to leaf and thus connect the latter with the soil.

The stem, then, is the great helping organ of the plant. The root, to fulfil its functions, must make its way downwards and explore the soil: the stem, to give the help demanded, must make its way upwards to the air and sunlight.

Observe that, unlike the root, the stem is jointed. Each joint is called a **node** (Fig. 1) and the space between, an **internode** (Fig. 1). Here again we may

observe adaptation to surroundings. If the plant is surrounded by other plants, or if it is grown with insufficient illumination, the internodes will lengthen enormously in the endeavour to carry the leaves up to the light. This is well seen in a potato allowed to sprout in a dark cupboard or in a bag.

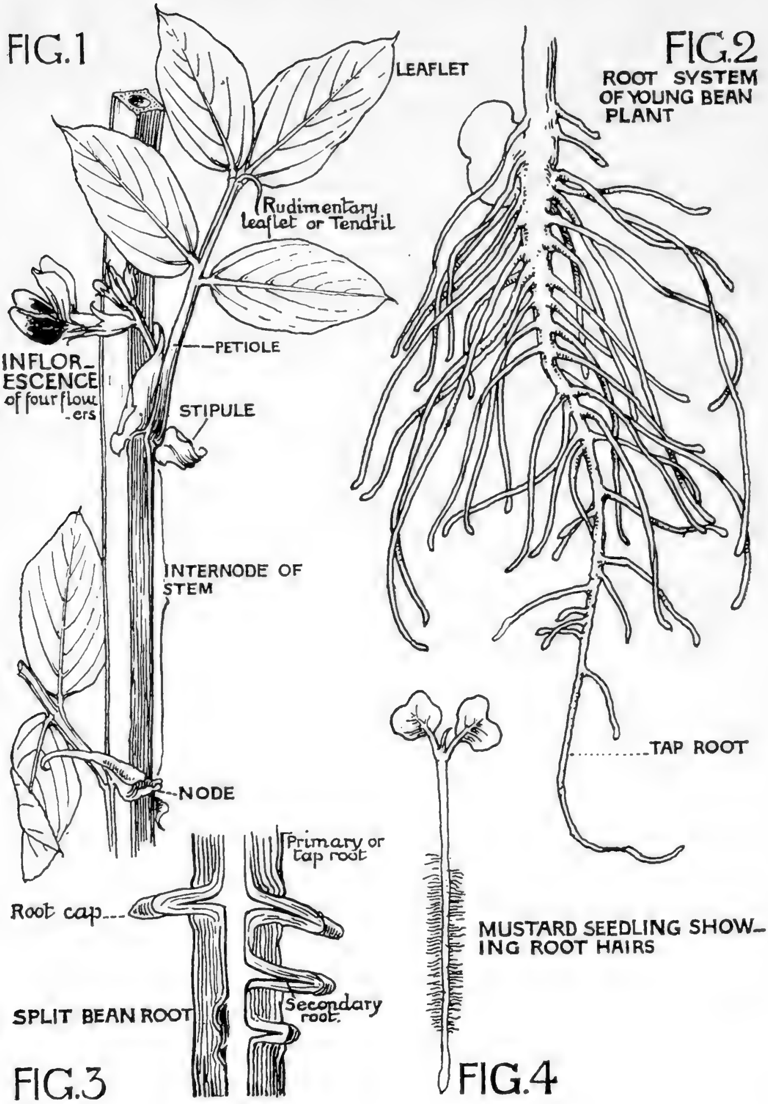
Note that, in the bean, the stem is square, though in most plants it is round. Such stem branches as are present are usually produced low down near the root, the higher nodes being occupied by flower-bearing shoots or inflorescences which after all, are only modifications of the former. Examine a number of other plants and observe that the stem branches arise in the axils of the leaves, *i.e.*, in the angle formed where the leaf-stalk meets the stem.

Now make a horizontal cut, almost severing a piece of young stem. Pull the upper part downwards in such a way as to skin off some of the outer delicate coat from the lower. This skin is colourless, and protects the inner tissues.

Next, completely sever the stem and note the thin green layer immediately inside the skin, and, beyond this, the ring of dark spots. The green tissue helps the leaves in their work, while the dark spots are really the cut ends of little strands of hard tissue that continue downwards to the root, and upwards to the leaf, where they branch into all the veins. Inside this ring is a layer of colourless tissue, and finally, in the middle, an open space. The bean stem then is hollow; but, by examining a number of other plants, it will be found that hollow stems are the exception rather than the rule.

3. **The Leaf** (Fig. 1). Before examining the bean leaf, look at a few simple leaves in which the blade is all in one piece. Take for instance those of the poplar, the so-called garden nasturtium (*Tropæolum*), the

VEGETATIVE ORGANS



mallow or the geranium. Observe the stalk or petiole by which the blade is held away from the stem and enabled to wave freely in the air and sunshine. Next examine the blade itself, which, being thin and flat, presents a surface, large in proportion to its weight, for the absorption of food and sunlight from the air. The ribs and veins, which branch finally into a delicate network and are continuous with the hard tissues of the stem and root, not only constitute the strengthening skeleton of the leaf, but form the channels by which the leaf is supplied with much of the raw material needed for the formation of those compounds of which the tissues are built, and through which much of the finished product is distributed throughout the plant. The green colour of the leaf arises from the presence of a highly complex substance called **chlorophyll,** without which the energy of the sunlight could not be utilised. All substances in the world are either **organic** or **inorganic**. Organic substances are those which are part of, or, at one time, in their present form, were part of, or were produced by some living thing. Thus, such things as wood, milk and sugar, are organic, while stone, air and water are inorganic. No true animal can form organic from inorganic substances. Only plants can do this. Thus no animal can form the substance of which its body is built without the help of plants. Plants must first form from the water, minerals and gases of the inorganic world, those organic compounds from which alone the animal can build its tissues and supply itself with the energy necessary for its life and work.

Animals then, receive from plants, either directly or indirectly, all their building material and energy. This brings us back again to the leaf, the factory of the plant, the organ in which is worked up the raw material from the earth and air to form these organic

substances that are essential to animal existence: and let us say at once that it is the chlorophyll alone that has the power of utilizing the sunlight which supplies the energy needed for this important work. Thus the chlorophyll is the one link between the world of lifeless matter and living animals.

Having now examined several simple leaves, let us see what peculiarities appear in the leaf of the bean. We observe first that the blade is not all in one piece, but consists of several leaflets. The midrib, which is really a continuation of the petiole, is quite free of the leaflet blades, while each leaflet has its own midrib, which branches like a feather to form the smaller ribs or veins. At the end of the main rib is a small loose end. This is really a much reduced leaflet, which, in many members of the bean family, as for instance the pea, is modified to form a tendril for climbing. Just where the petiole joins the stem are two small flat outgrowths. These are called **stipules** and do the work of protecting the young leaf while still a tender bud. At the same time, being green, they do some of the work of leaves.

Such permanent peculiarities as those we have noted are the result of changes that have taken place gradually in the course of ages, but there are also special variations that arise in the leaf when growing under unusual conditions. Thus, when growing in the dark, the petioles lengthen enormously in an effort to carry the blade out to the light, while the blade itself, since under such conditions it is a practically useless appendage, almost disappears. The plant responds to environment and expends its chief energy in the direction most likely to produce useful results.

Reproductive Organs.

While the vegetative organs are concerned chiefly in maintaining the life of the individual, the reproductive organs are devoted to the preservation of the race. In the bean plant, for instance, the flower, fruit and seed are produced in order that the race of bean plants may not disappear from the face of the earth, while the leaf, root and stem only indirectly serve this purpose by making provision for vigorous growth.

The reproductive organs form the link between one generation and another. They relate each generation to the generation that succeeds it.

1. **The Flower** (Fig. 5). In the bean, the flowers are arranged on little branches that appear in the axils of the upper leaves. Such a flowering branch is called an inflorescence. Each flower itself is really a modified branch and the different parts, sepals, petals, stamens and carpels, are really leaves that have been crowded close together and modified to do special work.

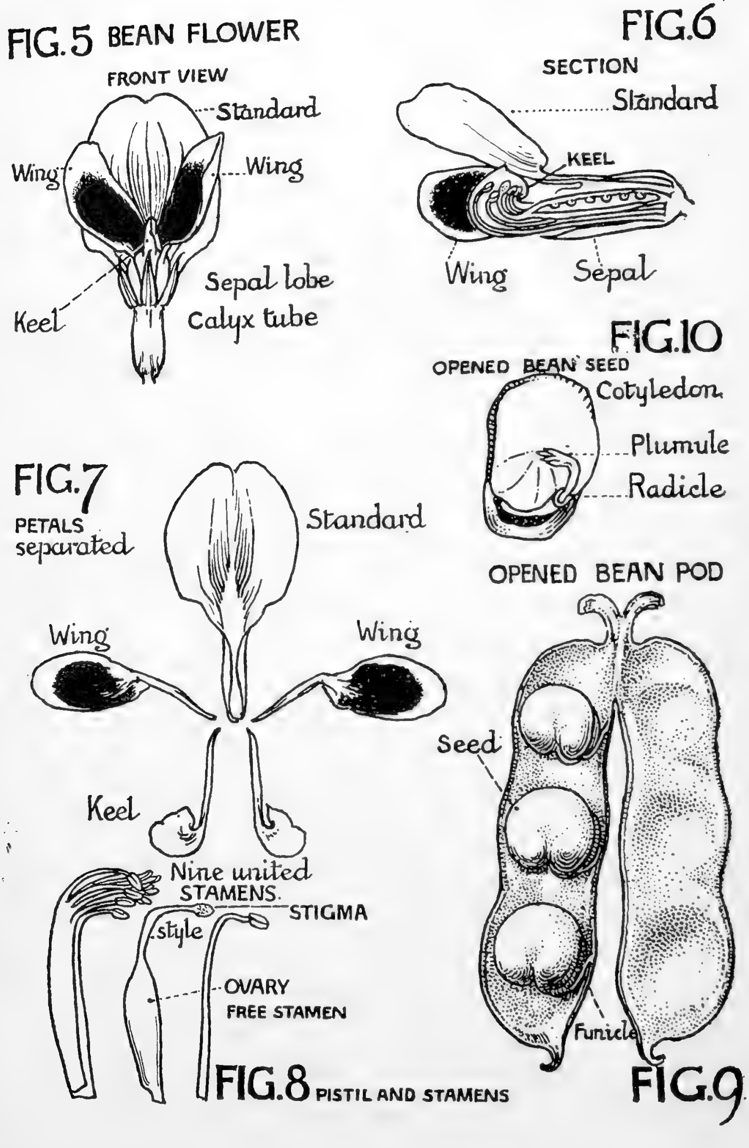
(*a*) **Sepals** (Figs. 5-6). At the base of each flower note the green or colourless cup showing on its upper edge five pointed lobes. This cup is the **calyx** (Fig. 5) and the five lobes show that it is made up of five united sepals. In many plants, such as the wallflower and buttercup, the sepals do not form a cup but are quite free and distinct. The function of the sepals is to protect the young flower in the bud, chiefly from cold. If a frost comes while the flower buds of the fruit trees are still covered by the sepals, but little harm is done, but if the flower be once expanded a frost is fatal.

Modifications of the calyx arise in the anemone and clematis, where, in the absence of petals, the sepals become large and showy to attract insects to the flower.

(*b*) **Petals** (Figs. 5-7). Fixed on the base of the calyx tube are the petals which collectively form the **corolla.** At the back is the broad standard, at the sides the wings, and in front, more or less enclosed by the wings, the two united petals that form the keel. This arrangement of the petals is peculiar to the bean, pea, and other members of this family. In the wall-flower and buttercup the petals are all of the same form and the corolla is therefore symmetrical. The chief function of the corolla is to render the flower visible from a distance, so that insects may see and visit it. These insects carry from the stamens of one flower to the carpels of another the yellow, dust-like pollen, without which no fruit can be formed. In the tutu a well known native tree the petals become fleshy and succulent, and by this modification help to form the fruit.

(*c*) **Stamens** (Figs. 6-8). In the bean, these lie inside the keel and appear as ten fine threads, nine united for some distance from the base to form an imperfect kind of tube, and one quite free. At the end of each slender thread or filament is a little knob, the anther, which contains the pollen. The stamen is the male organ of the flower, and the pollen its essential part. Each carpel or collection of carpels must receive some of this pollen or it will not develop into a fruit. The pollen is better seen in such flowers as the lily, iris or narcissus. The arrangement of stamens found in the bean flower is peculiar to that family. In the manuka or tea-tree, the buttercup and poppy, the filaments are free throughout their entire length. While still doing their own work, stamens may be modified to perform other functions. It is to the brightly coloured stamens alone that the rata owes the crimson blaze that

REPRODUCTIVE ORGANS



summons from afar the birds that are to be its pollen bearers.

(*d*) **Carpels.** In the bean, there is only one carpel and this constitutes the pistil of the flower. To examine this, break away the tube formed by the lower parts of the nine united stamens. The lower thicker part of the pistil is called the ovary. Split this and notice the ovules, which later on develop into seeds. At the end of the ovary is a more slender portion, the style, which is bent at right angles, and whose function is to place the stigma, the sticky part at the tip, in a suitable position for receiving the pollen carried to it by visiting insects. In most flowers we find more than one carpel, and these carpels may be united or free. In the former case, collectively they form the pistil (Fig. 8). In the buttercup and clematis the carpels are free and each has its own ovary, style and stigma In the lily, the three carpels are united to form a single body, in which the ovary shows three chambers or cells, and the stigma spreads out into three lobes at the tip of the single style, which has been formed by the fusion of the styles of the three original carpels. Though the true function of the carpels is to produce and protect the seed we find that, in the iris, parts of them, the styles, are large and brightly coloured, and thus assist the petals in their work.

2. **The Fruit** (Fig. 9) generally arises from the development of the ovary, though, as we have seen in the tutu, neighbouring structures may take part in its composition. The bean fruit is a pod which consists exclusively of the developed ovary and has the seeds attached in a row by funicles or little stalks to its interior surface. The shell of the pod is formed of the ovary wall which has become tough and firm to protect the seeds. In many cases, as in the cherry and blackberry, the fruit becomes succulent, and birds,

eating it, pass the stone undigested, and thus serve to distribute the seed. There is a vast variety of fruits, dry or succulent, light or heavy, solid or hollow, opening or non-opening—all adapted to the particular surroundings in which the plant and its ancestors have lived. To deal with the modification of fruits would be to anticipate the whole subject, so that further discussion must be left for another place.

3. **The Seed** (Fig. 10) can hardly be called an organ of the plant. It is in reality the form in which the individual plant sets free its offspring to battle for itself. It is the young plant of the new generation, together with a store of food provided by its parent to tide it over the initial difficulties of getting into due relation with its environment, in other words to feed it till it can gather food for itself.

Remove the skin from the bean seed and split apart the two fleshy seed leaves or cotyledons, which contain the store of reserve material with which the young plant begins its development. Between the cotyledons appears the tiny plant, even at this early stage showing a differentiation into radicle or young root and plumule or young stem. Further consideration of the seed will be deferred till we deal with germination.

At this stage it may be well once more to insist on the need for field botany. The student should first make himself familiar with the weeds and other wild plants in his garden or playground, then study those in waste places and by the roadside, and finally make expeditions to the bush, the marshes, and the seashore further to extend his knowledge. It will at first be impossible in most cases for him to name the specimens himself (for even an expert botanist may find it hard to identify an

unfamiliar plant) but in almost every district there are a few enthusiasts, who will be only too glad to assist, and if all else fails, the author will render what help he can.

From this point onwards it will be well to alternate the lessons on special topics such as germination and growth, with a general study of one or more of such plants as may happen to be in flower. Material for this purpose will be found in the section dealing with natural orders which is placed at the end of the book. Familiarity with a large number of types, and the consideration of whole plants, alternately with the detailed study of special organs, gives that breadth which an exclusive attention to detail is not unlikely to destroy.

Summary.

Vegetative Organs. **The Root** obtains water containing dissolved mineral salts from the soil. **The Stem** conducts these to the leaves and carries the organic materials manufactured there to the parts where they are required. The stem also spreads out the leaves to the air and sunlight. **The Leaf,** by means of its chlorophyll, uses the energy of the sunlight to build up organic compounds from the inorganic materials obtained from earth and air.

Reproductive Organs. **The Flower** consists of sepals which protect the young flower bud, of petals which attract insects, of stamens which produce the pollen, and of carpels which form the pistil and contain the ovules. **The Fruit** is the developed ovary, sometimes with the addition of neighbouring parts. It contains the seeds. **The Seed** is a young plant with a store of nourishment. Cotyledons, root and shoot are all present.

QUESTIONS ON CHAPTER I.

1. What is an organ? Name three organs found in animals and three found in plants.
2. What is meant by function? What are the chief functions of a bean plant?
3. Show that the bean plant is an organism.
4. When is the broad bean usually sown? When does it flower and when is the fruit ripe?
5. Contrast the root and stem of a bean plant, dealing with colour, shape, direction of growth, appendages, etc.
6. Sketch sections of the stem and root.
7. What happens when water is poured on a bean leaf? What does the result suggest to you?
8. Compare the bean leaf with that of any other plant.
9. Make sketches of a bean leaf.
10. What insects have you seen visiting the bean flower? Where do they alight?
11. What changes take place in the flower from the unfolding of the bud to the production of the ripe pod?
12. How does the bean pod open if left on the plant?
13. Draw a bean seed showing all the external features.
14. Take off the coat of a bean seed, separate the seed leaves and draw what you see.
15. What happens when a bean seed is soaked in water, and what when placed in the soil?
16. Show that all parts of a bean seedling are present in the seed.
17. Compare the seed-leaves of the bean with its foliage leaves.
18. Distinguish "Reproductive" and "Vegetative" organs. Classify the organs of a potato plant under these two heads and justify each item in your classification.
19. What is meant by environment? Justify the assertion that air, soil, water and climate are the most important factors in the environment of an ordinary green plant.

Chapter II.

THE SEED AND GERMINATION.

Preliminary.

Before dealing with the seed itself it will be necessary to learn how to test certain substances it contains, and to identify two gases, one needed for germination, the other produced thereby.

Oxygen may be prepared by heating in a test tube about a quarter of a teaspoonful of chlorate of potash mixed with a very small quantity of black oxide of manganese. After sufficient heating, a glowing splinter of wood plunged into the tube will burst into flame. Taking it for granted that the substance given off is oxygen, we have discovered the following facts. Oxygen is a colourless gas without taste or smell, and vigorously supports combustion. The fact that substances burn in ordinary air, though not so violently as in pure oxygen, would naturally lead us to suppose that the air is diluted oxygen. As a matter of fact, in five gallons of air we have about one gallon of oxygen, diluted with about four gallons of an inactive gas called nitrogen. Eight-ninths of the weight of water is also oxygen. Oxygen is a very active gas, combines readily with a great many substances, and, in the act of combination, gives off heat. This combining of oxygen with some other substance is called **oxidation**, and the substance with which it combines is said to be oxidised. Under certain circumstances, the oxidation may be very violent and produce, at a given moment, much heat and light. In such cases we call it burning. When coal burns in a fire we have this fierce oxidation. The oxygen of the air combines with

the coal very rapidly and much heat and light are produced. On the other hand, when oxygen combines with iron to form rust, we have slow oxidation, and, though the total heat given off is considerable, it is produced so slowly that the iron never gets appreciably hotter. Nevertheless, if a coil of fine wire be heated red-hot at one end and held in a jar of oxygen, it will burn fiercely and produce much heat in a short time. The great function of oxygen in the living world is to oxidise things and set free heat and other forms of energy. **Energy** is the power to do work. All know the work that can be done by the burning or oxidation of coal. The heat given off may be used to warm a room, drive a locomotive, or to produce the electricity necessary for lighting or for driving a tram car. Neither animals nor plants could exist without oxygen. Animals absorb it through their lungs and use it to oxidise the food they have taken through the mouth, and thus to set free the energy they need for the body work. Plants, as we shall see later, use oxygen for the same purpose.

Carbon is a solid substance found in every tissue that goes to make up plant or animal. The diamond is pure carbon, while graphite, charcoal, coal, and coke are more or less impure forms of the same substance. The presence of carbon in any organic material may be indicated by heating it in a test tube, when the presence of carbon is shown by the charring of the substance. Thus milk, meat, wood, leaves, sugar, starch, and bone will all char when heated, for all contain carbon. In most plants, at least one-half the dry weight consists of carbon.

Carbon-dioxide is a gas which is usually prepared in the laboratory by pouring hydrochloric acid on marble chips. If these materials are not available the student may, however, obtain the gas by pouring

vinegar on washing-soda in a test tube. Effervescence takes place owing to the bubbles of carbon-dioxide given off.

Carbon-dioxide is a very heavy gas, and can be readily poured from one vessel into another. Before pouring the vinegar on the soda have ready another test-tube containing about an inch of lime-water. Without allowing any of the liquid to pass over the lip, pour the gas from the first test tube into the second. On shaking the tube the lime-water becomes milky, and this milkiness is the recognised sign that carbon-dioxide is present. Now blow through a glass tube into clear lime-water, which, by becoming milky shows that the breath is heavily charged with carbon-dioxide. Next pour some lime-water into a shallow dish and expose it to the air. A milky scum soon forms on the top, showing that the air contains a certain amount of the same gas.

Now pour some lime-water into a jar of air, or better still, of oxygen. The liquid does not become milky, for in the small quantity of air enclosed in the jar there is not enough carbon-dioxide to produce an appreciable result. Now lower into the jar a burning candle, and withdraw it, when, having used up almost all the oxygen, it is about to go out. Then shake up the lime-water: it will become milky, showing that the carbon of the candle has combined with the oxygen to form carbon-dioxide. In the same way the carbon-dioxide of the breath is formed by the oxidation of the carbon in the food. It will be shown that a similar process of oxidation, producing carbon-dioxide, goes on in the plant.

Iodine in the dissolved state is used as a test for **Starch**, and may be prepared as follows:—

Dissolve a few crystals of potassium iodide in water, (about 1 gram to 75 c.c. of water), and add to this iodine crystals till the liquid is a dark brown.

To show the test, make a little thin starch paste. A single drop of iodine added to this will give a blue colour. In testing substances for starch, the best results are obtained by scraping the material very fine, boiling in a test tube with water, cooling by letting the tap run on the tube, and then adding the drop of iodine. The cooling is very important, for, when the material is above a certain temperature, the blue colour will not appear. Various substances, such as potato, parsnip, and seeds may be tested in this way.

Fehling's Solution is a substance used to test for **grape sugar,** which is present in various parts of plants.

The following rough and ready method of preparing the Solution will serve all practical purposes:—

Add tartaric acid to bluestone (copper sulphate) dissolved in water, till the colour is slightly green, and then add caustic soda till the solution is dark blue.

To show the test, crush a piece of apple or banana, cover with water, add a drop of Fehling's Solution and boil in a test tube; a yellow or orange red sediment is formed, showing the presence of grape sugar. The carbon of the sugar has taken away from the copper in the solution some of the oxygen that was united with it, and thus caused the change in colour from blue to yellow. In other words the higher oxide of copper has been reduced by the carbon of the sugar to a lower oxide, which, being insoluble, has been thrown down as a precipitate.

Carbohydrates are solid substances that consist of carbon combined with the elements of water or, since water is a compound of oxygen and hydrogen, carbohydrates may be said to be formed from carbon, oxygen, and hydrogen, the oxygen and hydrogen being in the same proportion as they are found in water. The most important carbohydrates are sugar, starch, and cellulose.

Sugar differs from the other two in being soluble and in having more oxygen and hydrogen in its composition. Sugar, as we shall find later, is abundant in most fruits as well as in many roots and succulent stems. **Starch** is insoluble in water and is present in most seeds and underground stems. **Cellulose** forms the bulk of all wood, while good filter paper as well as cotton wool are pure cellulose. The simpler tests for this substance are not always reliable, but the following can usually be applied with success:—

Soak the material to be tested, say cotton wool or filter paper, in weak iodine solution and then place on it a drop of strong sulphuric acid. A blue colour appears, which almost immediately changes to black. Where this blue colour shows itself we may be sure that cellulose is present, but where it is not seen we cannot be so sure that it is absent.

Oils, which, like carbohydrates, are composed of carbon, oxygen, and hydrogen, but in different proportions, are plentiful in many seeds. In seeds such as the castor bean the presence of oil may be shown by rubbing the broken surface of the seed on a piece of tissue paper. A transparent greasy mark shows that oil is there. Where not plentiful, the oil may be extracted by crushing and soaking a number of seeds in ether in a tightly corked test-tube. The ether dissolves out the oil: after allowing the tube to stand for some hours, pour off the ether without disturbing the sediment of crushed seed, and allow it to evaporate in a shallow dish. When the ether has disappeared drops of oil will remain.

Proteins are found in all plants. Carbohydrates and oils contain carbon, oxygen, and hydrogen. The same three substances are found in proteins, but in addition, the gas nitrogen, the mineral sulphur, and, as a rule, the element phosphorus enter into their composition. Proteins then, are the nitrogenous

compounds of plants. Place a drop of strong nitric acid on the white of a hard boiled egg. The yellow colour which appears shows the presence of a protein, in this case albumen. Now wash flour in a piece of fine muslin, till nothing but an elastic substance remains. This is gluten, another protein, which responds to the same test.

The **protoplasm** or living substance of both plants and animals is in the nature of a protein. Protoplasm is found only in living things, and there is no life without it. Indeed it is the life substance.

Seeds.

Have ready a number of seeds of different plants, some quite dry and others that have been soaked in water for twenty-four hours. Seeds of the broad bean, scarlet runner, pumpkin, sunflower, castor oil, onion, maize, and barley will be suitable for the purpose.

Examine a dry **bean** seed (Figs. 11-12). Observe that it is kidney-shaped and that it is covered with a brown coat, the **testa.** Note the black scar, the **hilum,** which shows where the seed was attached to the wall of the pod by a little stalk or **funicle.** Now take a seed that has been soaked, and, after drying, squeeze it between the finger and thumb. A drop of water will appear near one end of the hilum. This indicates the position of the **micropyle,** a small opening, through which, before it could develop into a seed, the ovule received a tube bearing fertilizing material from the pollen grain, and through which passes the bulk of the water absorbed by the seed.

Now remove the brown coat or testa which protects the more delicate parts within. Carefully separate the two fleshy **cotyledons** which contain the store of food that is to support the infant plant. Test the bean cotyledons for starch and protein. Both are present,

the protein being legumin, a substance of similar composition to the protein which forms the curd of milk. The legumin is so plentiful that a drop of nitric acid placed on the inner side of the cotyledon produces an intense yellow. Now examine the young plant that lies curved between the cotyledons. Observe that it is attached to both cotyledons at about its middle point. The portion above the point of attachment is the **plumule** or young stem, and, by examining this with a lens, the undeveloped leaves may be seen.

Immediately below the cotyledons is the **hypocotyl,** which in the broad bean never appreciably develops; but which, in the scarlet runner, pumpkin, and many other plants lengthens to such an extent as to lift the cotyledons well above the ground. In such cases the hypocotyl develops to form the lower part of the stem. Continuous with the hypocotyl, but showing no definite point of junction therewith, is the **radicle**, or young root. This points towards the micropyle, through which, under suitable conditions, it will, later on, emerge.

The cotyledons, plumule, hypocotyl, and radicle collectively form the **embryo** bean plant.

The so-called **sunflower** seed (Figs. 16-18) is really a fruit, in which the seed is still covered by the original seed case which has been formed from the ovary wall. Take one of the soaked specimens and observe that the seed case may be split along the edge. If this is done carefully it will be seen that the enclosed seed is attached to the pointed end by a very short stalk. On removing the thin seed-coat, separate the two cotyledons and observe the small plumule and radicle situated at the extremity of the pointed end. The iodine test shows that starch is absent from the cotyledons, but the nitric acid and tissue paper tests show that proteins and oil are abundant.

The **castor-oil** seed (Figs. 13-15) differs considerably from both bean and sunflower. At the pointed end is a spongy mass the **caruncle,** which rapidly absorbs water. If the seed be placed in hot water a bubble of air will come out of the micropyle, indicating that it is in the region of the caruncle. The advantage of this is obvious. On removing the skin it would appear as if there were not two cotyledons as in the bean and sunflower. As a matter of fact, in the castor oil bean the cotyledons are two flat bodies lying inside the oily mass that forms the bulk of the seed. This oily mass is called **endosperm**, and, like the cotyledons, serves to support the young plant. Seeds with endosperm are called albuminous while those without are termed exalbuminous.

In most dicotyledons, *i.e.*, plants that have two seed-leaves, the seeds are exalbuminous, while in all monocotyledons, *i.e.*, plants that have only one seed-leaf, they are albuminous. Now, with a sharp knife slice the castor seed longitudinally through its flatter sides into two fairly equal parts. As shown in Fig. 14, the cut edges of the two flat cotyledons will be seen with the radicle extending downwards from the point of junction below, and the tiny plumule pointing upwards just above it. Now slice another seed through its rounded sides as shown in Fig. 15. The desired result may not be attained till after several attempts, but finally, even without a lens, it should be possible to see the veining of the exposed surface of the cotyledon. The radicle appears below, and, with great care and patience, it will be possible so to split a seed as to see the plumule as well.

The reserve food in the endosperm consists of oil and protein, and does not respond to the test for starch. The cotyledons show abundant protein as well as oil.

It may be mentioned in passing that the scarlet outgrowth forming the cup of the titoki seed is similar

SEEDS

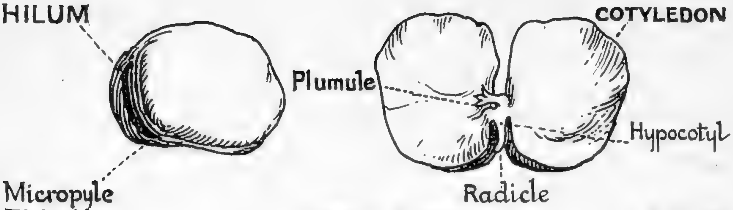


FIG. 11 — BEAN SEEDS — FIG. 12

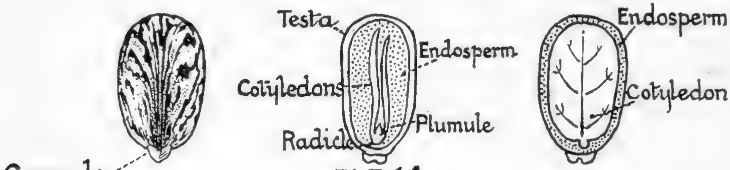


FIG. 14

FIG. 13 — CASTOR BEAN — FIG. 15

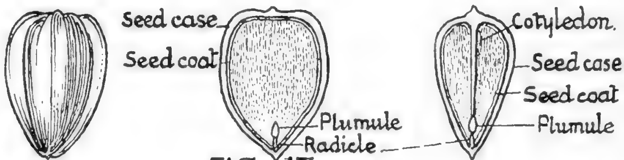


FIG. 17

FIG. 16 — SUN FLOWER FRUIT — FIG. 18

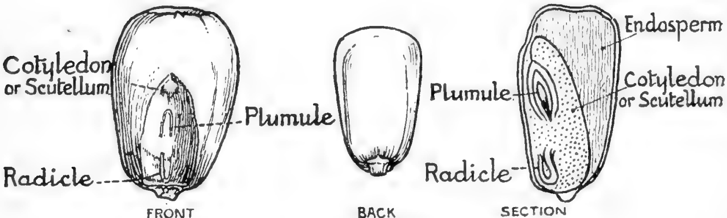


FIG. 20

FIG. 19 — MAIZE GRAIN — FIG. 21

to the caruncle of the castor bean, but, being much larger, is called an **aril**.

The **Maize** grain (Figs. 19-21) is a fruit and not a seed; but it differs from the fruit of the sunflower. Whereas, in the latter, the seed case is merely a loose covering which can be removed, in the former, this case has coalesced with the coat of the seed, and formed a single envelope which is firmly united with the food materials within. If on the growing corn-cob the development of the maize grain is carefully watched from day to day, it will be noted that there is no shedding of a seed case, and that therefore the ovary wall must fuse with the seed-coat and form part of the grain itself. Externally the grain is a blunt wedge-shaped body flattened on one side and having a rough apex which shows its point of attachment to the cob, and in which is the opening that corresponds with the micropyle of a dicotyledon. This may be located by placing the grain in hot water, when a bubble of air comes out as in the case of the castor bean. On the flat side, is a more or less triangular depression bisected vertically by a narrow ridge which indicates the position of the radicle and plumule. Now take a well-soaked grain, and, with a pin, prick away, from the side remote from the depression, the endosperm, which above and on the outside consists of amber-coloured matter, and further in of white easily powdered substance. In this way a tough elastic shield-shaped body will be exposed. This is the cotyledon, attached to the front of which may be seen the plumule and radicle forming a straight line on the flat side. Now split another grain through the flattened sides as shown in Fig. 21. In this, with the assistance of a lens, the structure of the young shoot may be seen. The iodine test shows that the endosperm is chiefly starch. When a drop of nitric acid is applied to the cut surface of the grain, the cotyledon becomes yellow, showing the

presence of protein, but the endosperm, except on its extreme outer edge, remains unchanged. Oil, though present, is not abundant. The foregoing investigations show that the true difference between monocotyledonous and dicotyledonous seeds is, as the names would suggest, that in the embryo of the former there is only one cotyledon, while in that of the latter there are two. Moreover, endosperm, which is present in all monocotyledons, is found in but few dicotyledons.

The **Coconut** is well worth study. It is really the kernel of the fruit, and, like a plum stone, consists of the seed contained in a hard shell. The white material that lines the shell and is eaten, is the endosperm, and the dark coat that adheres to it when it is broken away from the shell is really the seed coat. The germ is less than half an inch long, and is situated immediately beneath one of the three eyes, the substance of this eye being thin and soft, and on germination affording a means of exit for the plumule. In the hottest part of the summer, place a coconut in a box of sawdust and keep it in a warm place, watering it thoroughly from time to time with lukewarm water. At night, wrap the box in an old woollen rug. The seed will germinate and the plumule appear through the eye. Now break open the nut and note the huge sponge-like sucker that absorbs the milk and flesh to be conveyed in solution to the young seedling.

The **Date** stone is a seed in which the hard material is endosperm. The embryo plant lies at the back on the side opposite the groove a short distance below the middle. On cleaning a date seed a depression will be noted at the back, where by scraping with a knife, the embryo plant may be exposed. This lies in a small cavity, and the sprouting rootlet makes its way out through the thin covering at the depression. The whole embryo may be extracted by placing the edge of a pocket-knife in the groove, and giving the back of

the blade a sharp tap. The seed splits and sets free the embryo. It is difficult, even with a lens, to distinguish cotyledon, radicle, and plumule. Soak the split endosperm in weak iodine solution. The fact that there is no blue coloration shows that starch is absent. Now place on the split surface a drop of strong sulphuric acid and the blue colour which indicates the presence of cellulose immediately appears.

Speaking broadly, we have now arrived at the conclusion that the seed is really a young plant which, together with its store of nourishment, has been formed from the ovule of the flower while still attached to and forming part of the parent plant. At a certain stage, the development of the embryo plant ceases, and we say that the seed is ripe. All growth then stops, and the seed, becoming dry, goes into a resting condition. This temporary arrest of development is an obvious advantage. The seed can, to some extent, choose its own time for renewal of growth. If, in the autumn when most of the seeds fall from the parent plants, the embryo were still growing, it would mean that the young plant would have to establish itself under adverse conditions. Autumn, in many places, is the driest season of the year, and the tiny seedling would thus have to contend with scarcity of water, and later on be overwhelmed by the frosts and snows of winter. Instead, the embryo remains dormant till the warm spring rains supply the conditions most favourable to its growth.

The **Mangrove**, which grows on the mud-flats of the tidal inlets of the Auckland Peninsula, is modified to suit its peculiar environment. If the seed were dropped into the mud in an absolutely dormant state it would probably be carried out to sea before it had a chance to germinate. To avoid this, most mangroves show no arrest in the development of the embryo, growth being continuous from ovule to fully established tree.

In some species, the young plant becomes over a foot in length before detaching itself from the parent tree. Still growing, it falls into the mud, and, in the space of a few hours, is permanently established. The species that grows round the shores of Auckland Peninsula is peculiar in the fact that the seed does not fall out of the seed case, since the whole fruit detaches itself from the tree at one time. The seed does not escape till it reaches the water, when, under favourable conditions, though no radicle is present, it puts forth several slender roots that anchor the seedling to the mud. In the proper season, mangrove fruits may be commonly seen washing about along the shores of Waitemata harbour. When the seed case is removed the two large fleshy cotyledons appear, and the fact that there is no radicle may be readily observed.

Germination.

Let us now study the circumstances under which the embryo or infant plant resumes its interrupted development: in other words, let us consider the conditions necessary to germination, as the awakening of the seed is termed.

Moisture.—Every gardener knows that moisture is essential to germination. Seeds may be kept for years in a dry bag or box and there will be no sign of awakening: but only let the bag become wet, and, other conditions being favourable, germination will at once begin. The seedsman stores his seeds in a dry place so that they shall not germinate.

Experiment 1.—Place various kinds of seeds in moist sawdust and others on a dry shelf. The latter will not germinate, but if the weather is not too cold the former will.

Warmth is necessary. Everyone has observed that, in the colder parts of New Zealand, where a piece of

land has been dug or ploughed in late autumn, weed seedlings do not appear in any quantity till the winter frosts are over. No farmer thinks of sowing turnips at midwinter, while the tender French bean should not be put into the soil till all risk of frost is over. There is a **maximum** temperature above which, and a **minimum** below which germination will not take place. There is, moreover, an **optimum** temperature at which it proceeds most vigorously. These temperatures vary for different plants. In most plants cultivated in temperate regions vital activity is suspended below 40° F., while the maximum temperature is, in most cases, about 115° F. The optimum is between 80° and 95° according to the plant, wheat being 84° and maize 93°.

Experiment 2.—This experiment, which should be made in the summer time, can be carried out only where a refrigerator is working in the neighbourhood, and ice can, therefore, without difficulty, be obtained at a low cost. Place a block of ice, (about six-pennyworth will be enough) in a fair-sized box, pack it below and at the sides with moist sawdust, and lay upon it various kinds of seeds wrapped in a piece of damp cloth. Now cover the whole to the depth of several inches with more of the damp sawdust. The seeds are wrapped in cloth to prevent their being scattered as the ice melts. As required, renew the ice every few days for a fortnight. There will be no germination. This shows that seeds will not germinate at a temperature below freezing point. That the seeds are not killed is shown by the fact that they germinate when ice is no longer supplied. Experiments to discover the maximum, minimum, and optimum temperatures, by means of germination experiments carried out in chambers constantly kept at a certain temperature, would be far more instructive than the foregoing, but are obviously beyond the scope of an elementary course.

Oxygen.—Now make experiments to show whether air, or rather oxygen, is required.

Experiment 3.—Place bean and other seeds in a bottle of water which has been recently boiled for some time to expel air. See that the water reaches right to the mouth of the bottle and then cork it

GERMINATION

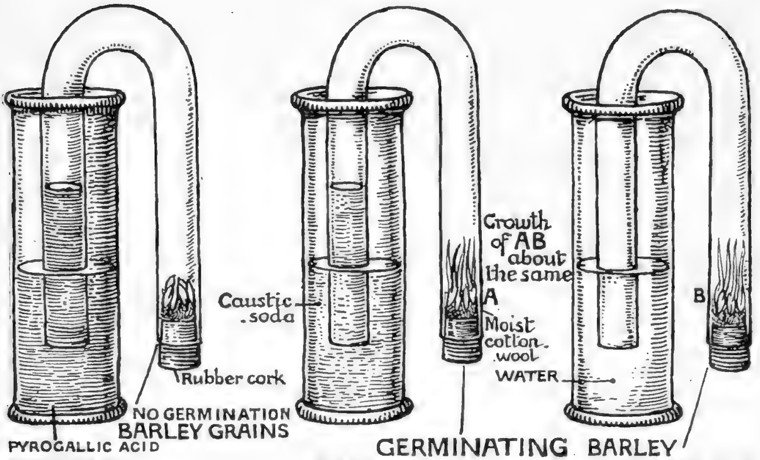


FIG.22 FIG.23 FIG.24

tightly. As a control (*i.e.*, standard of comparison) place seeds in unboiled water, and, leaving the bottle uncorked, from time to time bubble air with a pair of bellows or a syringe into the water. In the first bottle there will be no sign of germination, while in the second the seeds will sprout a little, though, owing to the limited supply of air, germination will not be very vigorous. We thus see that air, or one or more of its constituents, is necessary to germination.

Experiment 4 (Figs. 22-24).—Obtain three U tubes, place in one end of each, on moist cotton wool or rag,

a few barley grains. Have in three separate tumblers, or better still, gas jars, as shown in the figure, water, a solution of caustic soda, and a solution of pyrogallic acid in caustic soda respectively.

Now place the tubes with their clear ends dipping into the liquids, one in each jar. Then, with rubber corks, stop the ends containing the barley grains. The pyrogallic acid solution takes from the air in the tube the oxygen it contains, and, as about a fifth of the air is oxygen, the liquid, to fill the place of the gas, rises in the tube to occupy one-fifth of the space between the surface of the water and the cork. In this tube no germination will take place, no matter how long it may be left. It is to be noted that the oxygen is more readily absorbed if the inside of the tube is made wet with the solution at the clear end for about one-fifth of its length.

In the tube dipping into water germination proceeds to a certain extent, indeed, till the enclosed oxygen is exhausted. Though the oxygen is used, the water does not rise in the tube. This, as we shall discover later, is due to the fact that the oxygen is replaced by exactly the same volume of carbon dioxide.

In the tube dipping into caustic soda, germination proceeds to the same extent as in that dipping into water, but, since caustic soda absorbs carbon dioxide, the liquid gradually rises in the tube, till, by the time all the oxygen has been used and replaced by carbon dioxide, the space occupied by the liquid is again one-fifth of the tube.

Light is not necessary to germination, as might be supposed from the fact that seeds germinate when buried in the ground, provided they are not too deep to receive a sufficient supply of oxygen. Indeed, seedlings in their early stages, develop more rapidly in the dark than in the light. Experiments to show this are easily devised.

Phenomena of Germination.

Water.—The bean and other seeds, as well as the maize and barley grains, first absorb a great deal of water, swell, and become softer. This water is necessary to dissolve the food substances stored in the cotyledons and endosperm, for plants, like animals, can utilise food only when in solution. The seeds, when thus swelling, exert enormous **pressure.** Fill a narrow-necked bottle with peas, these being easier to get in than broad beans, and place the bottle, uncorked, in a vessel of water. The seeds on swelling fracture the glass of the bottle. Germinating seeds have been known to lift paving stones and break holes in asphalt paths.

That water enters chiefly through the micropyle may be proved as follows. Make two heaps of say twenty seeds. In each of the seeds of one heap block up the micropyle with bicycle cement. Now weigh and place each heap in a separate vessel of water. Remove from the water, wipe dry and weigh the seeds at intervals. It will be found that the seeds with free micropyles, owing to their faster absorption of water, gain weight far more rapidly than the others.

Growth.—The radicle now lengthens and makes its way through the micropyle, while the seed coat splits, and in some cases the cotyledons at once cast off the skin and separate to display the plumule between them. The different ways in which the shoot escapes from the cover will be dealt with later on.

Fermentation.—The cotyledon of a dry bean and the endosperm of maize have already been found to contain a copious supply of **starch.** Now, by means of Fehling's Solution, test them for sugar. Sugar, in appreciable quantity at any rate, is not present. Now take seeds, which, deep in the damp sawdust, have sprouted but not yet become green. On testing these,

sugar will be found to be present, especially in the radicle and plumule. This is what one would naturally expect. The insoluble starch has been converted into soluble sugar so that the plant can use it. Where changes such as this take place in an organic substance owing to the action of a living thing or something produced by a living thing, the process is known as fermentation. The conversion of the starch into sugar is due to a ferment called **diastase.** This ferment is particularly active in germinating barley, and rapidly changes most of the starch of the grain into sugar. It is on this circumstance that the malting of barley depends.

Now take a date stone that has been kept for a couple of weeks in damp sawdust. The endosperm will be found to have softened considerably, and, on being tested with Fehling's Solution, it will be seen that the **cellulose** has been largely converted into sugar. This is due to another ferment called **cytase**.

Oil itself is insoluble in water, and therefore the embryo in the castor oil seed cannot make use of this reserve material of the endosperm unless some form of fermentation takes place. As a matter of fact, the oil, by the agency of a ferment called **lipase**, is, at germination, split up into fatty acid and glycerine, both of which are soluble in water. This is well shown by the following experiment. Test linseed oil with blue and red litmus paper. As there is no result in either case, the oil is neither acid nor alkaline. In other words, it is neutral. Now crush germinating castor beans and add them to the oil. After a few hours the oil will turn blue litmus red, showing that the lipase has separated fatty acid from the glycerine.

Carbon dioxide.—We have already seen in the experiment with caustic soda that during germination carbon dioxide is formed. This fact may be more simply demonstrated. On a wet cloth in the bottom

of a pickle bottle, place some bean seeds. Cork with a rubber cork or an ordinary cork well smeared with vaseline to keep out the air. When the seeds have been germinating for some days pour the gas from the bottle into a test-tube containing a little lime water, which, on being shaken becomes milky, indicating the presence of carbon dioxide. As we shall find later on, some of the carbon of the seed has been oxidised to supply the energy necessary for the development of the embryo. At this stage of the plant's life, in the absence of chlorophyll, oxidation is the only available source of energy.

Heat.—Wherever oxidation takes place we may expect heat; but obviously the amount given off at one time by a single germinating seed would be too small sensibly to affect the thermometer. Fill two vessels holding at least a quart, one with germinating peas, and the other with moist cotton wool. Cover each with a sheet of cardboard supplied with a hole through which a thermometer may pass. Extremely accurate instruments, in which the temperature readings exactly correspond, are needed for this purpose. Pass the thermometers through the openings, placing the bulb of one in the heart of the germinating seeds, the other in the cotton wool. Accurate observations, in which care is taken not to breathe on or touch the apparatus, will show that the mercury stands higher in the thermometer registering the temperature of the mass of germinating peas than in the other. The writer has never observed a difference of more than one degree. The vessels must not, of course, be placed in the sunlight.

Escaping from the Cover.

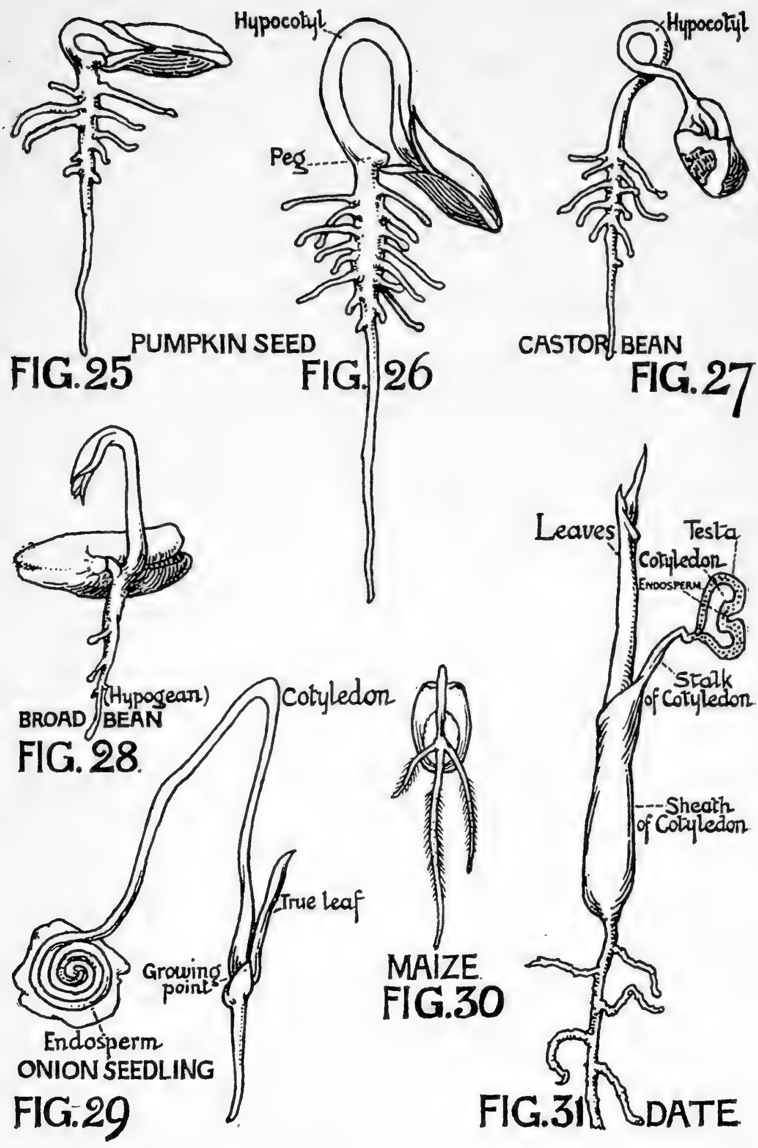
All seeds do not escape from their covers in the same way. Practically all dicotyledons and some monocotyledons back out of their covers, instead of

bursting away the skin and pushing with their tender growing points, to light, air, and freedom. If the delicate plumule were to be pushed upward through the rough soil it would be in danger of sustaining serious injury, but, when pulled out with the apex pointing into the earth, this danger is much reduced. By observing the illustrations it will be seen that there are two main methods of escape. A loop is formed either in the stem immediately above or in the hypocotyl immediately below the cotyledons. All depends on the position of this loop. When it is formed in the stem above the cotyledons the plumule alone is pulled from the ground, and the cotyledons remain in the earth. This type, well illustrated in the broad bean (Fig. 28), is called **hypogean** (Gk. *hypo* under, and *ge* the earth). Where the loop is formed in the hypocotyl the cotyledons are pulled out of the cover and appear above ground. This type, shown in the marrow, French bean, and castor bean (Figs. 25-27), is termed **epigean** (Gk. *epi* upon, and *ge* the earth). In the pumpkin, it will be observed, there is a remarkable peg which is of great assistance to the cotyledons in freeing themselves of their covers.

In most monocotyledons, such as maize (Fig. 30) and wheat, the plumule emerges from the seed and makes its way straight upwards into the air, but in the onion (Fig. 29) a most peculiar development takes place. The cotyledon itself, which is long and slender, forms a loop by means of which it backs out of the seed. The tip of the cotyledon remains for a considerable time, coiled like a watch-spring, embedded in the endosperm from which it absorbs nourishment till its final escape. Something very similar happens in the date (Fig. 31).

The net result of this investigation of seeds and their germination, is to show that, though the broad features are the same in all cases, yet each type has its

ESCAPING FROM THE COVER



PUMPKIN SEED FIG. 25

FIG. 26

CASTOR BEAN FIG. 27

BROAD BEAN FIG. 28

ONION SEEDLING FIG. 29

MAIZE FIG. 30

FIG. 31 DATE

own peculiar characteristics, which, as we shall see later, specially adapt the individual to its particular environment.

SUMMARY.

Oxygen, a gas that supports combustion. It oxidises carbon and other substances, and thus sets free energy.

Carbon is a solid found in all organic substances and forms half the dry weight of plants. Organic substances therefore char when heated.

Carbon-dioxide is a heavy gas which arises from the oxidation of carbon and is given off at germination. It turns lime-water milky.

Carbohydrates.—Starch, sugar, cellulose are composed of carbon, hydrogen, and oxygen.

Starch gives a blue colour with iodine. It is found in most seeds.

Grape sugar gives a yellow colour when boiled with Fehling's Solution. It is found in most fruits.

Cellulose, the chief constituent of wood, is pure in cotton wool. It gives a blue colour with iodine and sulphuric acid.

Oils are composed of C.O. and H., but not in the same proportion as carbohydrates. They are found in seeds.

Proteins are composed of C.O.H.N.S. They are in all parts of plants. Protoplasm, the life substance, is in the nature of a protein.

Bean Seed.—Testa, hilum, funicle, micropyle, two cotyledons, plumule, hypocotyl, radicle. Starch and protein are present.

Sunflower, a fruit, the seed being in a seed case—much oil.

Castor bean has oily endosperm. A caruncle is present.

Maize has only one cotyledon, but much starchy endosperm. Cotyledon and outer layer of endosperm contain protein.

Coconut is the inner part of a fruit. The flesh is the endosperm, and the germ is below the soft eye.

The **Date** is a seed with hard cellulose endosperm. The germ is just below the surface at the back.

A **Seed** is a young plant whose development has been arrested.

Germination requires moisture, warmth, and oxygen, but not light.

Phenomena.—Seeds absorb water and exert great pressure, the radicle and plumule escape. Reserve materials become soluble. By diastase starch is changed into sugar, by cytase cellulose into sugar, and by lipase oil into fatty acids and glycerine. Carbon dioxide is produced by oxidation of the carbon compounds of the seed to supply energy. Heat is produced by this oxidation.

Escape.—The plumule backs out of the cover. Where this is done by a loop formed above the cotyledons the cotyledons are left in the earth (hypogean), where formed in the hypocotyl the cotyledons come above ground (epigean). In the onion and date the cotyledon tip remains for some time embedded in the endosperm.

QUESTIONS ON CHAPTER II.

1. To what kinds of plants are seeds essential? Explain why some plants might do without seeds.
2. How are the delicate parts of a seed protected?
3. Describe a sunflower seed and compare it with a castor-bean.
4. Define hypocotyl, plumule, and seedling.
5. Compare a monocotylous with a dicotylous seed.

6. How would you prepare oxygen? What are the properties of the gas, and what is its use in germination?
7. Where and in what forms is carbon found in nature? What is the importance of carbon to a plant?
8. What tests do you use for starch, sugar, cellulose, solid protein, and oil?
9. What compounds did you find in the date stone, the castor-bean, and maize grain?
10. What are the conditions necessary to germination? How would you prove your assertions by experiment?
11. Has light any effect on germination?
12. What is diastase? What other similar substances do you know?
13. What are the phenomena of germination?
14. Define micropyle, testa, radicle, plumule, cotyledon.
15. How could you test the vitality of seeds?
16. Explain the importance of pure seed to the farmer.
17. Discuss the importance of seeds to man.
18. Describe the seeds of the coconut and date.
19. Why is the young plant in a seed said to be dormant?
20. Why do seedlings grow badly in soil that is too liberally watered?
21. How could you measure and compare the amount of air in different samples of soil?
22. Seeds should not be sown too deep or laid on the surface of the soil. Why?
23. How could you prove that a germinating seed loses weight in the darkness? Explain the reason of this.
24. Compare the food stored in a bean seed and wheat grain with that supplied to a young bird in an egg and to an infant in milk.
25. What is a carbohydrate? Mention the chief carbohydrates, stating how they are distinguished from one another.
26. What is the distinction between oils and carbohydrates? What tests may be used for oils?
27. How do proteins differ from carbohydrates? Give simple tests for proteins.
28. How are the reserve food-substances present in a seed made available for the nourishment of the seedling?

29. How does the shoot of a young broad bean seedling make its way out of the soil? Compare the method of emergence of the bean shoot with that of the pumpkin, onion and wheat shoots.
30. What is the difference between endospermic (albuminous) and non-endospermic (ex-albuminous) seeds? Show that both kinds of seeds may contain the same kind of food.
31. In a lesson on germination to a class of children between the ages of 10 and 12 what points would you deal with, and what material could you select for practical work?
32. Explain the terms oxidation, slow oxidation, burning. Give two examples of each.
33. Explain the relation between oxidation and energy. Whence do animals derive the energy necessary for the carrying out of their vital processes?
34. What intimate relation exists between plants and animals? Show particularly how plants form the connecting link between living animals and the world of inorganic matter.
35. What are the special functions of the following parts of an ordinary seed:—testa, micropyle, cotyledon, endosperm, radicle, plumule, hypocotyl?
36. Compare the embryo in a pea seed with that in a wheat grain.
37. What is meant by fermentation? Give common examples of the process.
38. In what special way is the mangrove seed adapted to its environment? Explain fully the advantage of the adaptation.
39. Why is germination alluded to as the awakening of the young plant?
40. How would you show that a considerable quantity of carbon dioxide is produced at germination? Describe two methods.
41. How would you show the action of diastase, cytase, and lipase respectively?
42. How would you show that heat is evolved during the process of germination? What gives rise to this heat?
43. In what respects is the behaviour of the onion seed on germination similar to that of a date stone?
44. Distinguish the terms "hypogean" and "epigean" as applied to the escape of the shoot of a seedling from its cover. Has either method of escape an advantage over the other?

Chapter III.

THE ROOT.

The root, we have seen, is the organ that relates the plant to the soil, by means of which it is held firmly in position, and through which it receives its supplies of water and minerals. It now remains to examine in detail the different structures that comprise the root, to study their origin, growth, and development, and, above all, to discover the function of each. We shall thus see how the root helps to fit the plant to its environment, always remembering that it is with the soil, which forms but part of that environment, that this organ is principally concerned.

We have already noted the lavish root production in certain well known plants, and the enormous length that the roots may collectively attain. We shall now see how, and in what order they are produced. Obtain two boxes each with one sloping glass side. Fill these with loose moist soil, and against the glass, just below the surface of the soil, place in the first, two or three well soaked broad bean seeds (Fig. 32), and in the second, the same number of maize grains. Cover both boxes with a black cloth, so that no light may reach the germinating seeds. Observations made from time to time show that first the tiny radicle appears, and, no matter in what direction it may escape from the micropyle, it will eventually make its way straight downwards along the surface of the glass. Up to this stage, except in point of size, there is no notable difference between the rootlets of bean and maize, but soon we come to the parting of the ways. In the bean, the radicle becomes thicker, lengthens indefinitely and gives off side branches in regular succession, so that

it gives rise to the whole root system of the plant. In the maize, on the other hand, though the radicle may lengthen considerably and branch to a certain extent, it remains thin and fibrous and forms but a portion of the root system. Shortly, **adventitious roots** (i.e., roots not given off in regular succession from a tap root) arise from the stem at the bases of the lower leaves.

If a box of the kind described is not available, a glass jar lined with blotting paper and filled with moist sawdust may be used, the seeds being placed between the blotting paper and the glass.

In the bean, and indeed most dicotyledons, the elongated radicle forms the **primary** or **tap root**, which bores deep into the soil, and, by throwing off secondary, which in their turn give rise to tertiary roots, forms a root system of great extent. Indeed, the branching may be continued indefinitely till almost every soil particle in the neighbourhood of the plant is in contact with the hairs of one or more of the spreading rootlets. The adventitious roots of the maize or any other monocotyledon, form, on the other hand, a dense fibrous mass, and, though the fibres thoroughly explore a certain soil region, they do not penetrate so deeply as the root of the ordinary dicotyledonous plant.

There are, however, even dicotyledons in which the tap root, after penetrating the earth for a little distance, goes no further, but leaves to its branches the work of gathering the food the plant requires. These surface feeders are well seen in the forest undergrowth, where they flourish side by side with the mighty trees, deep-feeders that make their way to the lower strata of the soil. Thus every soil-region is laid under contribution. The oak is a deep-feeder and the pine a surface-feeder. Hence, while the former is hardly ever uprooted even

by the fiercest storm, it is no uncommon thing to see numbers of pinus insignis, so plentiful in some parts of New Zealand, overthrown, even by a moderate gale, especially if from an unusual quarter.

Growth (Fig. 35). We have seen that when the seed germinates both plumule and radicle grow or become larger, and it might be supposed that this growth takes place in all parts of each. Take a well-grown bean seedling, and, with Indian ink, mark along the stem and root lines about a millimetre apart. Now hang the seedling with its root in a bottle with a little water in the bottom, so that, being in a moist atmosphere, it will not suffer for want of water. After a day or two it will present the appearance shown in the figure. It appears that the young plant has not grown equally in all parts. The marks which are now widest apart are those just behind the root tip and those nearest the apex of the stem. Thus there are two definite regions of elongation, one just behind the growing point of the root and the other just behind that of the stem. Here is the **meristem.**

The meristem, as indeed practically the whole of the plant, is composed of extremely small cells or boxes with living contents. In the meristem these boxes are being constantly split in two by new walls. It is clear that if nothing else happened the new cells thus formed would each be only half as large as the original cell, and would therefore occupy collectively only the same room. But each daughter cell enlarges till it becomes as big as its parent, and in this way growth takes place. Thus in the root, the cells which are being constantly cut off from the back of the growing point enlarge and cause elongation in this region. Those that are cut off from the front form the root-cap, but there is no elongation here, for, as we have already seen, these cells are being continually removed by friction.

Tropisms.

The Greek word *trope* means a turning. When a plant organ turns towards the thing that causes the turning the tropism is positive, and when it turns away from the thing the tropism is negative.

Geotropism. We have already seen that, in an ordinary plant, the stem grows upwards into the air and the root downwards into the soil. Thus the root is positively and the stem negatively geotropic, (*i.e.*, the former turns towards and the other away from the centre of the earth). Many experiments may be made to demonstrate this fact.

Stick a few mustard seeds on a thick piece of moist black cloth fixed in the bottom of a large glass capsule (*i.e.*, a round glass box with a lid to it) and then wire the lid on and hang the capsule vertically. In the course of a day or two the seeds will germinate. The root will travel unerringly downwards, and the plumule as unerringly upwards along the surface of the cloth, against which the mass of root hairs presents a strikingly beautiful sight (Fig. 40).

If broad bean seedlings that are well established are taken from the soil and planted upside down so that the roots point upwards and the stems downwards, it will be found that the roots and stems will bend round till they are again travelling in their original directions, the former towards the centre of the earth and the latter away from it (Fig. 36). The great advantage, indeed the necessity of these particular tropisms of root and stem must be obvious, for no matter in what position the seeds may germinate, the organ that is concerned in the light and air relations makes its way to the region where these things are most abundant, while that which relates the plant to the soil, places itself in the best position for that purpose.

An ingenious contrivance, the **clinostat** (Figs. 33-34) has been devised to prove that geotropy is due to the force of gravity.

Obtain a cheap clock with strong works. Strength rather than accuracy is needed. Get a watchmaker to replace the axle to which the minute hand is attached, with a spindle carrying at its extremity a light metal plate. Obtain a light glass jar as shown in the figure, and a cork to fit it. To one side of the cork fix several layers of damp blotting paper, and to this pin young pea seedlings with their radicles pointing towards the circumference, and their plumules towards the centre. Cork the jar, with the side bearing the peas inwards, and then fix the jar to the spindle of the clock by means of drawing pins pushed into the cork and overlapping the metal plate with their edges. Set the clock going, and have as a control another jar carrying seeds in a similar way but not rotating. In the first jar both roots and stems will continue in their original directions, while in the second the roots will turn downwards and the stems upwards (Fig. 34). Of course, the result shown in the drawings is an ideal rarely, if ever, attained. It would appear, nevertheless, that it is the force of gravity that causes the root to travel towards, and the stem to travel away from the centre of the earth. When any particular seedling was being carried up the left side of the clock the force of gravity exerted a pull on its root and evidently a repulsion on its stem. When, however, the same seedling was travelling down the right side, though gravity exerted the pull and repulsion in the same directions as before, the seedling, it must be remembered, had been turned over, so that the effect of the force would be to correct the tendency to bend acquired in the first half revolution. Thus when the influence of gravity is eliminated or neutralized there is neither positive nor negative geotropy,

GEOTROPISM

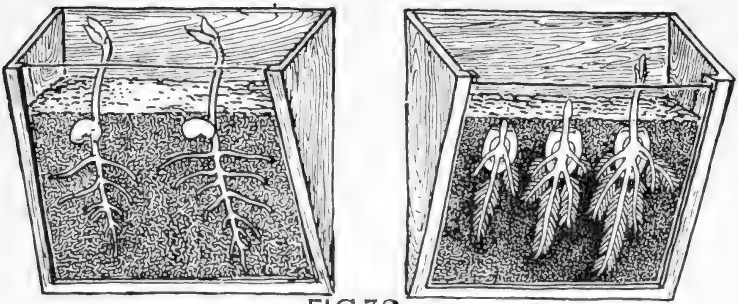
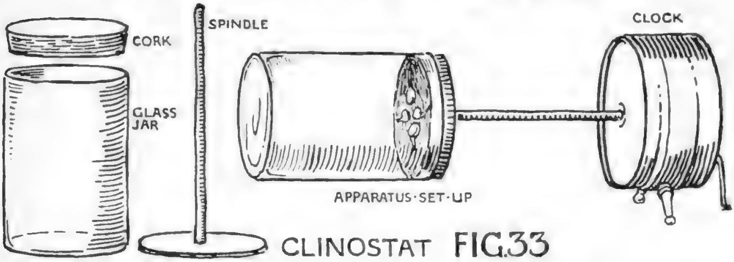


FIG.32



CLINOSTAT FIG.33

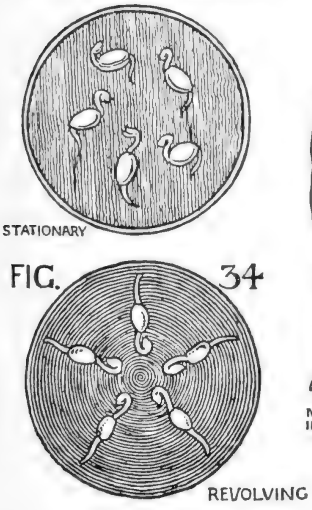


FIG. 34

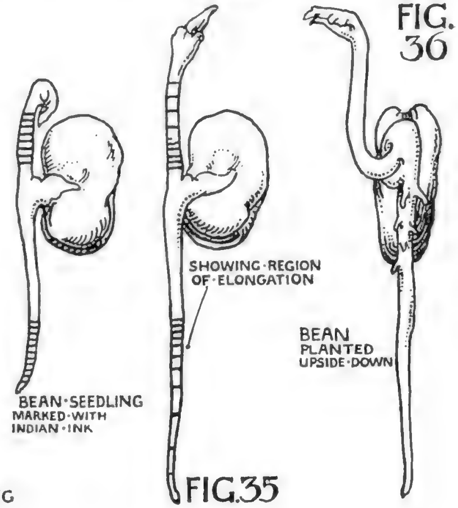


FIG.35

FIG. 36

and hence it is reasonable to suppose that gravity is the cause of these phenomena.

An important practical detail must be observed in using the apparatus. The jar soon becomes filled with carbon dioxide given off by the germinating seeds and thus growth is checked. If, however, the experimenter is careful to uncork the jar and turn it upside down for a few seconds each day at the time of winding the clock this difficulty will not arise. If it were not that evaporation on the surface of the blotting paper would cause the seedlings to shrivel, there would be no need for the jar at all. Indeed, there is a form of apparatus, in which, by allowing the seeds to dip, at the lowest point of their course, into a dish of water, the jar may be dispensed with altogether.

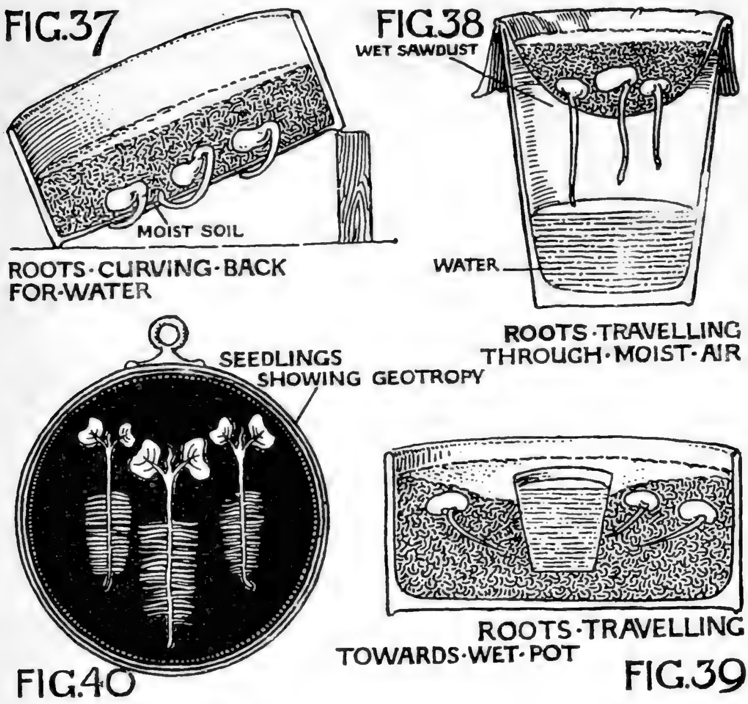
Hydrotropism (Gk. *hydor* water). Gravity is not the only stimulus or influence to which the root responds. It is obvious that the geotropic habit of the root adapts it to the gathering of the minerals and moisture which are present in the earth. Since the deeper regions of the soil usually contain more moisture, it is, as a rule, an advantage to the plant for the root to travel there. But it is clear that there will be cases where, as in the neighbourhood of a drain or a small spring, water is available without the customary boring. In such cases it would appear that there is competition between the pull of the water, and the pull of gravity. The following experiments will illustrate this.

Sow bean seeds in a box of moist earth in which the bottom is formed of fine wire netting. Tilt the box as shown in the figure, and cover with a dark cloth to exclude the influence of light. It will be found that the roots, after protruding through the wire, turn back again into the moist earth (Fig. 37). The impetus derived from gravity was sufficient to carry them through the wire, but gravity could not continue

to pull them down against the opposite pull of the water in the earth.

When however gravity and water pull in the same direction the root travels downwards. Fill a tumbler about a quarter full of water, and tie over the top

HYDROTROPISM



a piece of butter muslin, allowing it to sag in the middle. On the muslin, in damp sawdust, place germinating beans, allowing the radicle to protrude through the muslin into the glass. Cover the glass with a cloth and keep the sawdust moist. The roots will not change their direction, but will continue to travel downwards

towards the water through the moist air in the glass (Fig. 38).

A more striking experiment may be made by filling a box with sawdust only slightly damp. In the middle of this have a porous pot into which water may be poured. A flower pot, the hole in which has been tightly corked, will do quite well. Now place in the sawdust, at varying distances from the pot, germinating beans, taking care that in each case the radicle is pointing downwards. It will be found that the rootlets will turn towards the water in the pot (Fig. 39), water, as already seen, exerting a stronger pull than gravity.

The distances over which the roots of willow and other trees make their way to a stream or pond, and the manner in which they get into and block up the drains will be familiar to all.

Heliotropism (Gk. *helios* the sun) is the turning towards the light. That the stem is positively heliotropic (*i.e.*, that it turns towards the light) must have been observed by all who have grown plants in a window. This response to light on the part of the stem has the effect of presenting to the rays the broad flat surfaces of the leaves, an obvious advantage, seeing that it is with the light relation that the leaf is chiefly concerned. That the root is negatively heliotropic might be inferred from the fact that the adventitious roots on the ivy stem always turn away from the light, but the following experiment is more conclusive.

Obtain a large fruit jar, cover it, except for a narrow vertical strip, with black paper. Now hang through a large cork firmly fixed to the top of the jar a bean seedling in such a way that its root is opposite the slit. It will be found that the root soon turns away from the slit and withdraws itself as much as possible from the light. After the root has bent, it

may best be seen by scraping the paper off the jar on the side opposite the slit.

The turning away of the root from the light is exactly what one would expect, since water is generally to be found in the soil where no light exists. Light would, as it were, act as warning to the root that it was in the neighbourhood of a region where water would not be plentiful. The root is not, of course, conscious of the warning but is so constituted that it responds as though it were. These tropisms of roots are due to the irritability of the protoplasm, *i.e.*, the power of the protoplasm to respond to external influences.

Root Cap.—The root, we have seen, bores its way into the ground. In its course, it must, of necessity, push against the soil grains, and may, quite frequently, come into contact with hard stones and rock. Now, wherever growth is actually taking place, the tissue or substance of the plant is very soft and delicate, as may be seen by splitting the tip of a young twig, or cutting through the extremity of a root-branch of any common plant. This soft, actively dividing tissue where new growth is going on is the **meristem**. In the case of the stem, the meristem of the growing point is protected by the arching leaves of the bud in which it terminates, and, since the stem does not have to push its way through solid soil, this is quite sufficient. The root has no such leafy armour, but is provided instead with a root-cap, which serves it better. The growing point, where lies the soft actively dividing tissue that forms new cells, is not at the extreme tip, but a little way behind it, and is protected by similar cells, which, cut off from the front of the meristem, have become firmer and been pushed outward to form a kind of barrier against the rough soil grains. This barrier is the root-cap, the outer surface of which is being constantly worn away by friction with the soil, and

as constantly replaced by fresh portions supplied from the meristem behind it. In pulling plants from the soil, the root-cap is almost sure to be broken from the tip of every root branch, but there are circumstances under which this structure can be seen. Some members of the screw-pine family, to which the kie-kie belongs, send out from their upper parts, roots which pass downwards through the air to the earth below. On the tips of these the root-cap is quite a conspicuous object. The kie-kie itself does not produce these prop-roots. It may also be observed without a microscope on the roots of Wandering Jew grown in a jar of water. The root-cap fits over the growing point just as a thimble fits over and protects the finger.

Root Hairs. Having followed the root into the soil and seen how admirably it is suited for its work of boring, let us now examine the structures by which it is enabled to take advantage of the position it has attained, that is, see by what means it is able to gather for the use of the plant the water and minerals with which it has placed itself in contact. This brings us to the root hairs, which, just behind the growing points of roots and root branches, form a dense furry mass almost as compact as the pile on velvet. The mustard seedlings as shown in Fig. 40 with the root hairs displayed against the dark background of the cloth, present an appearance of wonderful beauty, and at the same time strikingly exhibit Nature's prodigality in providing for the needs of her children.

Roughly speaking, each hair is a little closed tube with very thin walls, so thin, indeed, that, by a process called **osmosis,** the water containing dissolved minerals is, under certain conditions, able to pass through from soil to plant, and certain waste products of the plant are able to pass outwards to the soil. Wherever two liquids or gases of different density are separated by a permeable membrane osmosis takes place. At present

ROOT HAIRS

FIG. 41

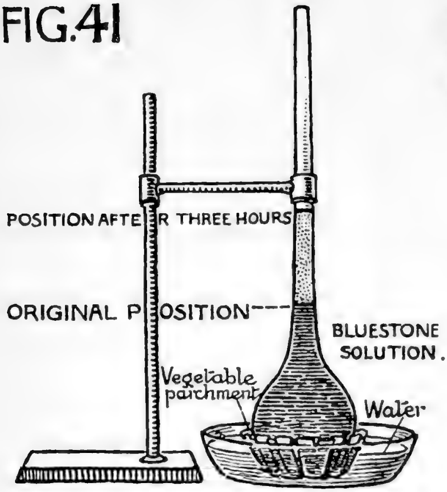


FIG. 43

FIG. 42

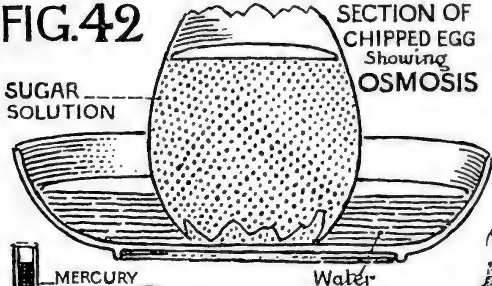
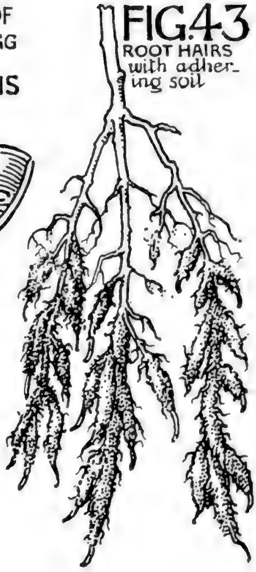


FIG. 43



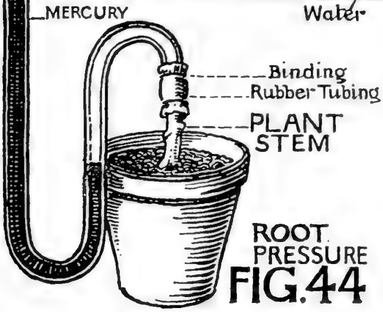


FIG. 44

we are dealing only with liquids. The chief point to be noted is that the less dense liquid passes through the membrane more rapidly than the more dense, as the following experiments will show.

Cover the mouth of a thistle funnel (Fig. 41) with vegetable parchment, fixed firmly to the rim and made absolutely air-tight with marine glue. Now fill the cup and part of the tube with strong bluestone solution, fix and stand the funnel with the parchment-covered end dipping into water. The liquid will soon begin to rise in the tube, showing that by osmosis the water is passing through the membrane into the funnel. At the same time the slightly bluish coloration of the liquid shows that some, though a lesser quantity, of the solution has passed out into the water. The liquid may not begin to rise in the tube immediately, since the parchment may continue to sag for a short time; but if left for a few hours a satisfactory result will always be obtained, provided that the parchment covering is air-tight.

As there is some little difficulty in fixing this apparatus, the following simpler illustration may be employed. Chip the shell off the bottom of an egg (Fig. 42) in such a way as not to injure the delicate membrane within. Now open the top of the egg, remove the contents, and place inside the shell several teaspoonfuls of a strong solution of grape sugar. Stand the egg with the exposed membrane below just dipping into a dish of water. The water will enter the egg shell, and, if sugar be added to keep up the strength of the solution, will eventually fill the interior and overflow. By testing the water in the dish it will be found that some of the sugar solution has passed through the membrane outwards. Incidentally, by adding a little starch paste to the solution in the egg shell, it may be shown, by means of the Fehling's

solution and iodine tests, that, while sugar passes readily, starch will not pass through a permeable membrane. This shows the purpose served at germination by the conversion of starch into sugar. Inside the root hair there is a condition of things very similar to that existing inside the eggshell, for the hair contains a solution of sugar and other substances, which causes the less dense solution of minerals to pass inwards from the soil.

There is another point which must be considered here. Whereas the apparatus we have used has no life, the root hair is a living cell and the protoplasm within exerts a more or less selective influence in connection with the absorption that takes place. Certain substances are not taken in at all, or are absorbed only in small quantities, while different plants, differing as to their requirements, take their food elements in different proportions from the soil. It is on this circumstance that the rotation of crops is based.

Root hairs are very short lived, as a rule lasting only a few days. As the root tip is constantly pushed forward the hairs behind disappear and new ones are continually formed behind the growing point. This is an advantage to the plant in two ways. The hairs are constantly exploring newer and fresher soil areas, and are removed from contact with certain injurious substances they themselves excrete or send out into the soil.

In pulling up a plant from the earth, the root hairs, owing to their close adherence to the soil grains, are almost invariably broken off, and where, as in very loose soil, they may be got out uninjured, they will carry with them numerous particles of the soil itself (Fig. 43). This intimate contact between root hairs and soil grains is a great advantage to the plant, for it is the invisible film of water that surrounds each

grain that is richest in the dissolved substances that the plant requires.

Root Pressure.—It is clear that the force exerted by the liquid pressing inwards through the membrane in both thistle funnel and egg, must be considerable, since it is enough to hold up a long column of water above the level of that which surrounds the base. This pressure could of course be measured. The liquid passing into the root hairs exerts a similar pressure, the effect of which may be readily seen in the bleeding of vine, peach, and other stems when cut in the spring. This bleeding is due to the osmotic pressure inwards and upwards from the root hairs. This root pressure may be measured by the apparatus shown in Fig. 44. The stem of a fuchsia or other suitable plant growing strongly in a pot is cut off a few inches above the ground and a glass tube, bent in the form of a flat S, as shown in the figure, is, by means of a piece of rubber tubing, firmly fixed to the stump. Now pour mercury into the tube till it stands somewhere near the top of the middle limb. The mercury will at first stand at the same level in both limbs. If the plant be well supplied with water, root pressure will however soon force the sap out from the cut end, and this, filling the part of the tube above the mercury, presses on the surface of the latter, and forces it up the left hand limb. In a few days the mercury will reach its highest point, upon which, by finding the weight of the mercury in the left hand limb and subtracting from it the weight of the water and mercury in the middle limb, the amount of the root pressure may be found. The length of the mercury and water columns and the bore of the tube must of course be measured. Then, taking the weight of 1 c.c. of water as 1 gram and the weight of mercury, volume for volume, 13·6 times that of water, the necessary calculation may easily be made.

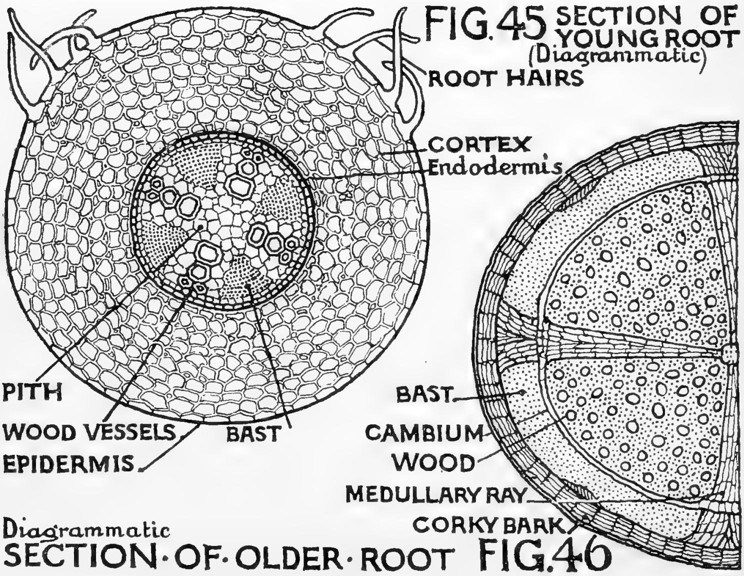
Arrangement of Tissues.

To consider the path taken by the absorbed liquid from the root hairs to the stem for transmission to the leaves, we must now examine the arrangement of the tissues of the root. If we cut across the root of a young bean plant somewhat beyond the seedling stage we shall see that in the middle is a harder denser portion which forms the **stele** or vascular cylinder. Outside this is a ring of softer tissue, the **cortex**, and the whole is enclosed in a thin skin, the **epidermis.** The latter, however, is not so easy to peel off as in the stem. Now, with a wet razor, cut a number of very thin sections or slices (Fig. 45) from the severed end of the root (which must also be kept wet) and place them on a small piece of glass, moistening them with water to prevent their drying up. When held against a good light and examined with a hand lens, the essential points of tissue arrangement and structure may be seen. If the first sections are not satisfactory cut others, remembering always to keep razor and root as wet as possible. The tissues will appear to be perforated by numberless little openings separated from each other by very thin dividing walls. These are in most cases the cells which contain the living and active materials of the plant. They are really little closed boxes, generally with very thin walls, which have been sliced through by the razor. These will be seen to vary in size and appearance in the different layers of the root. In other words, in passing in from the epidermis to the centre of the stele, different **tissues** will be observed, a tissue being regarded as one kind of living material, doing work more or less peculiar to itself.

The **epidermis** is chiefly protective, but just behind the growing points of all roots and root branches the cells of the epidermis lengthen outwards to form the all-important root hairs by which the absorbing surface is enormously increased.

The **cortex** consists of fairly large cells, through the thin walls of which the nutritive substances can easily pass by osmosis from the root hairs to the stele within. The stele is enclosed in a single layer of cells the **endodermis,** which, however, it will not with certainty be possible to distinguish with a hand lens.

SECTIONS OF ROOTS



Diagrammatic
SECTION·OF·OLDER·ROOT FIG. 46

The **stele,** it will be observed, has four, sometimes five groups of rather large openings. These are the vessels of the **wood,** and are really minute tubes which pass upwards through the stem and terminate in the smallest veins of the leaf. The patches of tissue that alternate with these groups form the **bast.** With an ordinary hand lens it is not, as a rule, possible to discern the cellular structure of the bast. In the middle of

the stele is the **pith,** a large-celled tissue appearing something like the cortex. There is no difficulty in observing all these details provided the section is cut thin enough. Don't try to cut the section as you would a slice of bread, but just slide the wet razor along the flat surface of the severed end without trying to cut anything, and then, by accident as it were, you will get a slice sufficiently thin.

The **functions** of the wood and bast may to a certain extent be observed. Hang a young bean plant with the lower parts of its roots dipping into a solution of eosin or red ink. After a few hours cut sections, beginning a little way above the root tip, and examine these with a good lens. It will be found that the red colouring matter has passed into the root hairs and made its way through to the vessels of the wood, and, above a certain point, it is only in these vessels that it will appear. By cutting further sections the path of the coloured liquid may be traced upward along the vessels from root to stem. Moreover, if some of the plants be left long enough in the solution, the red colouring matter will appear in the veins of the leaves, showing that these are continuous with the wood vessels of root and stem. It is therefore evident that the function of the vessels of the wood is to conduct water containing dissolved minerals from root to leaves.

The functions of the bast and cortex, though not a simple thing to demonstrate in the case of either root or stem, are more easily investigated in the latter. Ring a branch of a tree (*i.e.*, cut away the cortex and bast). Leave the tree for a year and examine the branch again. It will be found that below the ring there has been no increase in girth, while above, development has proceeded almost as before. The absence of growth below the ring indicates that the nutritive materials built up in the leaves were unable to pass the cut and hence must have formerly travelled

through the cortex or bast or through both, since these are the tissues removed. Careful experiment has shown that the proteins travel down the bast and the carbohydrates down the cortex. The bast then conducts proteins and the cortex carbohydrates. This **translocation current** or flow of organic matter built in the leaf is directed towards such parts of the plant as require these materials for storage or growth.

The epidermis, as we have already seen, is partly protective and partly absorptive. The pith may at times contain a store of reserve material, but more often its cells lose their protoplasm and hence cease to live.

In the bean and other **dicotyledons,** as the root develops, there is formed a ring of secondary meristem called **cambium,** which, pushing the bast outwards, forms a ring between wood and bast, so that in the older root these tissues instead of being arranged alternately are so placed that the latter lies outside the former. The cambium, by constant division, adds to the bast on the outside and to the wood on the inside, and in this way the root is thickened. At the same time the endodermis, cortex, and epidermis disappear, being replaced by a corky bark (Fig. 46).

In its early stages the root structure of a **monocotyledon** is practically the same as that of a dicotyledon, though there will as a rule be more wood groups than in the latter. The most important difference, however, is that **no cambium** is formed, and hence there is no provision for thickening. This accounts for the thin fibrous nature of the roots of most monocotyledons.

Types of Roots.

We have seen that there are two main types of root systems, the tap-root and the adventitious. Tap-root systems are best adapted to plants that require

ROOTS

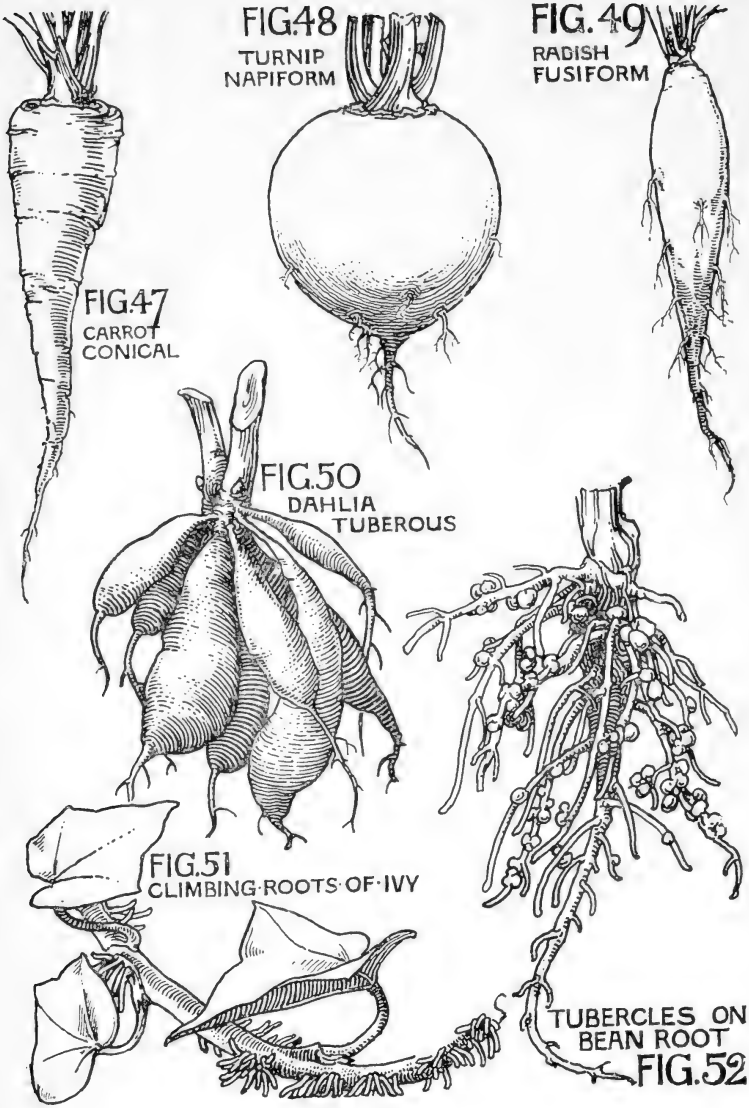


FIG.47
CARROT
CONICAL
FIG.48
TURNIP
NAPIFORM
FIG. 49
RADISH
FUSIFORM
FIG.50
DAHLIA
TUBEROUS
FIG.51
CLIMBING·ROOTS·OF·IVY
TUBERCLES ON
BEAN ROOT
FIG.52

a large and constant supply of water, and so must obtain it from the deeper regions of the soil where water is always present. Such plants, even though, like the trees of some tropical **forests**, they receive no rain for long periods together, continue to flourish, since they tap the accumulated supply derived from previous rains.

Grasses, with their fibrous roots penetrating but a short distance below the surface, are best suited to regions where rainfall, though not copious, is well distributed throughout the year. As a rule, the roots of ordinary cultivated crops do not penetrate the soil to a greater depth than three or four feet, but, in dry regions, in their search for moisture they may travel down for ten or twelve feet. Lucerne growing on dry soil has been known to penetrate over thirty feet.

There are various peculiarities found in the roots of certain plants which have arisen to adapt them to carry out special functions that are not ordinarily included in the work of this organ. The two chief **adaptations** of roots are for the storing of reserves of nourishment, and for climbing. In the **napiform** root of the turnip (Fig. 48), the **conical** root of the carrot (Fig. 47), and the **fusiform** root of the radish (Fig. 49), as in the case of many other biennials, reserve food is stored up in the first year to supply the material for the production of flower and fruit in the second; while in the **tuberous** roots of the dahlia (Fig. 50) a similar reserve supplies nourishment to the tiny shoots, that, in the spring, appear at the base of the old stem and provide for vegetative reproduction. In the ivy, the adventitious roots (Fig. 51) produced on the stem enable the plant to fix itself to walls, trees and other objects, and thus, in spite of its slender stem, to lift itself up for air and sunlight.

We have already noted, on the roots of the bean and other plants of the same family, the tubercles

(Fig. 52) that form the home of myriads of bacteria, which, as we shall see, help the plant to get the nitrogen it needs.

The roots of the **mangrove** have remarkable peculiarities to adapt them to their semi-aquatic habit. In the first place a number of so-called prop-roots are produced by offshoots from the stem growing downwards and fixing themselves in the mud to stay

L. Cockayne, Ph.D., F.R.S.

Breathing roots and young plants of Mangrove *(Avicennia officinalis)*.

the plant and form a buttress against the violence of storm or tide. Then, at some distance from the base of the stem, are produced green upright growths which are really root-tips, that, because of their unusual environment, have become negatively geotropic to perform new functions. Not only do they break the force of the waves, but, by means of pores, with which they are plentifully supplied, provide for the ingress of the air to the parts below water. They are really breathing roots. Being green, they also, doubtless,

help the leaves in their work. In the soft mud, moreover, there is no special need to protect the tender growing point, and hence, in the mangrove, the root-cap has been dispensed with.

In many **orchids,** such as the native dendrobium and earina, the roots do not bury themselves in soil, but, clinging to some tree trunk, absorb, by means of a surface layer of spongy tissue, any particles of water that may drip upon them.

Chemical Constituents of Plants.

All plants are built up of organic compounds formed from the inorganic substances derived from earth and air. To analyse the plant and identify the various elements that go to the building of these compounds requires a knowledge of chemistry far beyond the scope of this book. We shall therefore merely give certain more or less rule-of-thumb methods of testing for their presence and indicating their composition.

Carbohydrates. For starch, sugar, and cellulose the tests have already been given. In the dahlia and Jerusalem artichoke we find stored **inulin**, another carbohydrate which does not respond in the ordinary way to either iodine or Fehling's Solution test. Crush a dahlia root with a little water, filter off the liquid into a test-tube, and add methylated spirit. A dense white precipitate shows the presence of inulin. Now add iodine and the precipitate becomes yellow.

Oils and their composition have received attention in an earlier chapter.

Proteins, such as gluten and legumin have already been dealt with. Many proteins contain, in addition to the carbon, oxygen, hydrogen, nitrogen, and sulphur already mentioned, varying quantities of **phosphorus.** By strongly heating in a test-tube, the gluten of wheat or the cotyledon of a bean seed, the presence of sulphur

may be shown by the fact that the vapour given off will tarnish a silver spoon much in the same way as it is tarnished by the sulphur of an egg.

Elements.—Chemical analysis of a plant shows that it contains the elements, carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, iron, and, in some cases, silicon and chlorine. Of these, if we leave out of consideration the oxygen used in respiration, all, with the exception of carbon, come from the earth—the oxygen and hydrogen from the soil-water; nitrogen from the nitrates and ammonia compounds; potassium, calcium, magnesium and iron from nitrates, sulphates and phosphates; sulphur from sulphates; phosphorus from phosphates; chlorine from chlorides; and silicon from silicates. The carbon, which, as we have seen, forms the bulk of the plant, comes, of course, from the carbon-dioxide of the air.

Nitrogen is an inactive gas forming four-fifths of the volume of the air. By far the simplest way of extracting this gas from air is to moisten with ammonium chloride solution and sprinkle the inside of a bell jar with iron filings, and then stand the jar in a dish of water and firmly stopper it. In the course of a few days the oxygen in the jar combines with the iron to form iron oxide or rust, and the water rises one-fifth of the way up on the inside to take its place. The remaining four-fifths is nitrogen. If water be now poured into the dish till the liquid stands at the same level inside as outside the jar, and a lighted taper inserted, the taper will at once be extinguished. The level of the water outside must be raised to prevent the entry of air into the jar when the stopper is removed. The result of this experiment is to show that the air is about four-fifths nitrogen and one-fifth oxygen, and that nitrogen will not support combustion. Nitrate of

soda and sulphate of ammonia are the chief nitrogenous manures.

Phosphorus is, or used to be, the chief substance employed in making match-heads. It is plentiful in bones, and is generally supplied by the farmer to his plants in the form of superphosphate, basic slag, and bone dust. The ordinary form of phosphorus ignites at a very low temperature.

Potassium, the chief constituent of all potash manures, abounds in the ash of many plants. Kainit and sulphate of potash are used to supply this element to agricultural crops.

Calcium is the basis of lime, which consists of calcium and oxygen. Limestone, of which marble is a special form, is lime combined with carbon dioxide. The carbon dioxide may be driven off by heating the stone, when lime or calcium oxide remains.

Magnesium, better known in the form of magnesia, its oxide, is of less importance than any other of the foregoing elements.

Iron, though only traces of it are present in ordinary plants, is of great importance. It is the most widely distributed of all the metals, and is abundant in practically all soils.

Silicon combined with oxygen forms silica, found in nature as quartz, flint, and sand. It is the chief constituent of the hard outer coat of grasses and of the cutting edge found on the leaves of many sedges.

Chlorine is a gas which, combined with the metal sodium, forms common salt. Though it is essential to plants of the buckwheat family, it is, generally speaking, of little importance to agriculture. It may be prepared by heating a mixture of strong hydrochloric acid and manganese dioxide in a test tube. It acts on and destroys the lining of the air passages, but does serious harm only when liberated in considerable quantities.

The Soil.

The basis of ordinary garden soil, as of most other soils, is decomposed, or broken down rock. This forms its mineral, or **inorganic** constituent. **Organic** material, derived from decomposing plant and animal products, is also present, forming what is called the **humus.** There is, moreover, a certain amount of **water,** and, in addition, countless myriads of **bacteria** and **moulds** that are busy breaking up the organic compounds and making them ready for green plants.

To estimate the water, weigh as expeditiously as possible a portion of the soil to be investigated, and then leave it for several days spread out exposed to the air. The loss observed on re-weighing will give the weight of water held in the pores between the soil grains. A smaller portion of this air-dried soil may now be ground fine, weighed, and placed in a drying oven, which is kept at a temperature of 100° C. by a jacket of boiling water. After some hours re-weigh the soil. The loss of weight indicates the moisture held, even in the driest weather, as an invisible film on the surface of the soil grains. To determine the percentage of humus the dry soil derived from the last experiment must be burned. It may be mentioned that, in order to secure complete combustion, a large blowpipe, or, better still, a furnace is required. Owing to lack of apparatus the last experiment will doubtless be omitted in many cases.

Mechanical analysis of a soil is a long and tedious process but there are rough methods by which general structure may be determined. Make or obtain a number of small sieves, using wire gauze of the following meshes:—5 m.m., 3 m.m., 1 m.m., ·2 m.m. The last mesh is that used for testing the fineness of basic slag. Weigh out 100 grams of soil and stir it up with water in a glass vessel. Allow it to stand for 10

minutes and then pour off the liquid. Repeat this process till the water comes off clear. Dry and weigh the residue. The loss of weight in grams gives the percentage of the smaller particles, chiefly clay and silt. Now fix the sieves on a stand one above the other, the largest mesh on top, and the rest in descending order of size. Place a tray below the bottom sieve.

Place the dried residue on the topmost sieve and rub it with the fingers. Stones will be left on the 5 m.m. sieve, coarse gravel on the 3 m.m., fine gravel on the 1 m.m., coarse sand on the ·2 m.m., and fine sand on the tray. The different grades may now be weighed and the percentage thus arrived at.

By placing the various grains in a long glass tube, the smallest at the bottom and the rest in ascending order, a permanent and instructive record is secured. (Fig. 53).

The nature of the particles in any soil depends on the nature of the rock from which it is derived and the extent to which that rock is decomposed or broken up.

Rocks which, like granite, contain, among other things, particles of quartz or silica, are by various agencies broken down into a mixture of sand and clay. The particles of silica go to form grains of sand, for silica, unlike most rock-forming minerals, does not readily decompose. Such a soil, when supplied with humus, constitutes **a loam.** Rocks, which, like the basalts of the Auckland Peninsula, contain no free silica, eventually decompose into pure clays. The clays of the northern gum lands, though transported by water from the localities where they were formed, evidently originated in this way.

The so-called volcanic soils of the same districts consist really of decomposed, mixed with pieces of undecomposed basalt.

The chief minerals present in granite are potash-felspar and mica, while those found in basalt are lime-soda-felspar, augite and iron oxide. These minerals supply the bulk of the potassium, calcium, magnesium and iron essential to the growth of plants. Associated with the foregoing substances are the small quantities of phosphates and sulphates that provide the necessary phosphorus and sulphur. The decomposition of these rocks is brought about chiefly by the action of carbonic acid on the potash, lime and magnesia of the constituent minerals.

It will be noted that so far there is no mention of **nitrogen**. This element is in most cases derived from the humus and is organic in its origin. How then did plants get a footing on the earth before there were living things to produce organic matter for the formation of humus? It would appear that certain bacteria differ from green plants in having the power to assimilate the free nitrogen of the air. These probably existed in the early stages of the earth's history, and, as they died and decomposed, gradually formed a humus that prepared the way for the vast variety of green plants we see to-day. It is clear then, that in soil and air are contained all the elements necessary to build the plant body.

Soils are classified in accordance with the amount of sand, clay, lime and humus they happen to contain. A **sandy** soil is more than three-quarters sand, and a **clay** soil more than three-quarters clay. The former, though self-draining and easy to work, does not hold the necessary moisture, while the latter, though tenacious of water, is hard to work, apt to become sticky, and, above all, does not contain the air necessary to the work of roots. The ideal soil is a loam, or a mixture of about equal parts of sand and clay with the addition of a fair amount of humus. In limestone country, **marl**, a soil of which at least a quarter is limestone, may be found. **Peaty** soils are those which

have an undue proportion of humus, and exist on the sites of old swamps where raupo has, for centuries, grown up, died, and decomposed.

Root-acid.—From the very nature of the root hair it is clear that the food of the plant can pass into it only when in solution. Now, though many of the soil minerals are, to a slight extent, soluble in water, there are others that require an acid to bring them into solution. This acid is supplied by the root hairs themselves. Allow the roots of the bean seedling to grow over damp blue litmus paper. This, by becoming red at the points of contact, shows that an acid is exuded. Often the red colour will appear shortly after contact. Dissolve gelatine in a white saucer of hot water (ten grams of gelatine to 50 c.c. of water), add litmus solution, and then drop in limewater till the solution is blue. Just before the gelatine sets, place in it the roots of strongly-growing bean seedlings. When the material is cold these will be held firmly in position. The change of colour from blue to red in the neighbourhood of the roots affords a striking and beautiful proof that acid is being excreted.

Place on the surface of a piece of highly polished marble a number of mustard seeds, cover with damp sawdust and keep them damp for about a week. Now wash the marble, dry, and rub on it some vermilion. When the powder is brushed off, the areas where the root acid has eaten in will at once appear. To identify this acid, hang a strongly growing bean seedling with its roots in a bottle full of limewater, taking care that the cork is so fixed that very little air can come into contact with the liquid. The limewater becomes milky, showing that carbon dioxide is present. ~~Now the only acid that contains carbon-dioxide~~ is **carbonic acid**, ~~and hence it may be assumed that the root gives out carbonic acid. This is a compound of carbon dioxide and water, and the fact that carbon dioxide is formed in~~

Since CO_2 combines with water to form carbonic acid it may be assumed that one at any rate of the active acids formed in the region of the root is carbonic acid. The fact that CO_2 is evolved from

the root shows that here again respiration is taking place. Carbon is here combining with oxygen to supply the energy needed by the root to do its work. Carbonic acid is not the only acid given off by the root. From the fact that respiration takes place in the root, it may be inferred that oxygen is needed by that organ, and simple observations go to show that such is the case. Where the roots of plants are in water-logged soil, or where the soil is so compressed as not to admit of the free ingress of air, they become stunted and unhealthy, and the whole plant suffers. This incidentally draws attention to the fact, that, however necessary water may be, a soil may contain too much water; and, further, emphasizes the need for working a soil to loosen it and admit the air.

Water is held in the soil in three ways, first as free or **gravitational** water, which has sunk deep into the lower regions of the soil and there forms the chief reservoir of supply for trees and other deep-rooting plants. There is then the **capillary** water which is lifted from the reservoir below by the tube-like passages that wind among the soil grains, and supplies the grass and other surface feeders. Lastly **hygroscopic** moisture forms an invisible film round the apparently dry soil grains, and probably resists all efforts of the root hairs to withdraw it from the soil. To regulate the supply of moisture and let air into the roots of plants it is often necessary to resort to drainage. This results in keeping the free or gravitational moisture from getting so near the surface as to drive out the air from those soil regions that are occupied by the roots of ordinary farm crops.

Nitrogen Absorption.

Nitrogen is of prime importance to the plant, for it is the essential constituent of the life substance

protoplasm, as well as of all other proteins. Though nitrogen forms four-fifths of the atmosphere, green plants are not able to make use of the free nitrogen of the air. It is only through the medium of humus they can obtain it. On decomposing, the organic matter of the soil sets free ammonia, a gas consisting of nitrogen in combination with hydrogen. This unites with the oxygen of the air to form nitric acid, and the nitric acid combines with some substance like lime or potash to form a nitrate. It is in the form of a soluble nitrate that the green plant obtains its nitrogen.

Saltpetre is potassium nitrate, and is one of the forms of nitrogen available to the plant. Nitrate of soda, or Chile saltpetre, is another compound that serves the same purpose, being largely used as a manure.

There are plants which obtain the bulk of their nitrogen from the bodies of insects and small animals which they entrap. The **sundew** (Figs. 54-55) which grows plentifully on the poor lands from North Cape to Banks Peninsula is a good example of this. The leaves of the plant are divided into narrow segments and exude a glistening liquid, which, having the appearance of nectar, attracts insects. As soon as the insect settles, it is caught by the sticky dew and the leaf segments curl over and hold it tight. There is then poured on it a juice like the gastric juice of an animal, which dissolves the soft parts. The solution is then absorbed by the plant, and the leaf once more opens out ready for another victim. Sundews, because of their insectivorous habit, can grow on land poor in nitrogen.

Parasites are plants which do not gather and prepare food for themselves, but penetrate with their roots the tissues of other plants and absorb from them the sap containing the nutritive materials they need. Plants that are completely parasitic, then, get their

PLANT AND SOIL

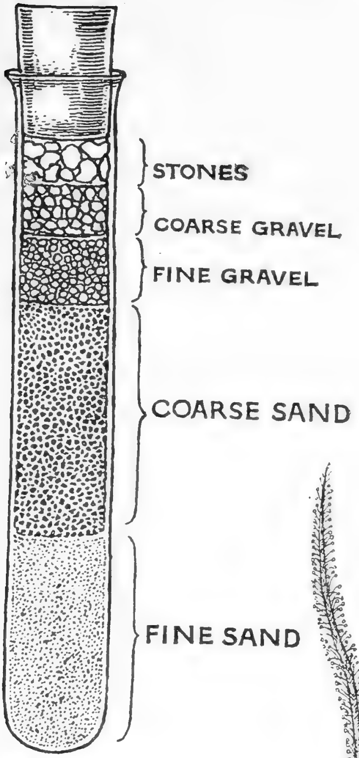


FIG. 53
MECHANICAL ANALYSIS OF SOIL

FIG. 54 SUNDEW DROSERA BINATA

FIG. 55 SUNDEW

SUNDEW DROSERA AURICULATA

nitrogen as well as the rest of their food from the host on which they live.

Certain **Bacteria**, which live on the roots of the bean and other plants of that family, have the power of taking free nitrogen from the air and building it up into the substance of their bodies. When these bacteria die, they form humus, which eventually produces nitrates available for the plant. It is for this reason that plants like clover and lucerne can, if properly treated, grow on soil poor in nitrogen.

Water Cultures.

By growing plants in distilled water to which certain mineral substances have been added, it is possible to discover the relative importance of the different elements that go to make a perfect plant food. Since the carbon of the plant comes from the air, and its oxygen and hydrogen from the water it only remains to supply its nitrogen, potassium, phosphorus, sulphur, calcium, magnesium and iron. **Knop's Solution** consists of 2 grm. of calcium nitrate, and ·5 grm. each of potassium nitrate, magnesium sulphate; and potassium phosphate with a few drops of iron chloride, all dissolved in four or five litres of distilled water.

Now take eight equal sized shoots of Wandering Jew. Place one in a solution to which all of the above substances have been added. To deprive one shoot of potassium use sodium nitrate instead of potassium nitrate and calcium phosphate instead of potassium phosphate. Deprive others of calcium by omitting calcium nitrate, of phosphorus by omitting the potassium phosphate, of magnesium by using calcium sulphate in place of magnesium sulphate; of sulphur, by using magnesium chloride instead of the sulphate; of nitrogen, by using potassium chloride and calcium sulphate in place of calcium and potassium nitrate;

and of iron, by omitting the iron chloride. Shoots may also be grown in distilled water and filtered tap water. These experiments in water culture will show that, generally speaking, the absence of nitrogen has the most serious effect, that of phosphorus

T. L. Lancaster, B.Sc., photo

Mustard plants grown in culture solutions.

the next, and that of potassium next. Sulphur, too, is shown to be fairly important, while, without iron, the leaves become pale and sickly looking. Calcium does not appear to be so important as the elements above-mentioned, while the absence of magnesium

seems to press less hardly than that of any other element.

The following satisfactory method may also be employed. Split ordinary corks into strips about half an inch in thickness, and from these make little rafts by uniting them in pairs with the splints of wooden matches. Float one raft on each solution and place across the splints of each a small piece of butter muslin in such a way that its ends hang into the liquid. Now place on each piece of muslin a few mustard seeds. These, being supplied with moisture by the water lifted by the muslin, soon germinate, and, by the varying vigour of their growth, indicate the relative importance of the different elements the solutions contain. It must be remembered that any seedling is able after germination to grow for a time by drawing on the reserves of food contained in the seed.

Summary.

The Root fixes the plant in the soil and procures its nourishment therefrom. Most dicotyledons have a tap root, and most monocotyledons adventitious roots. The root is positively, the stem negatively **geotropic**. Gravity attracts the one and repels the other. The root is positively **hydrotropic**. The root is negatively and the stem positively **heliotropic.** The **Root-cap** protects the meristem of the growing point. **Elongation** takes place just behind the growing point. **Root-hairs** are cells of the epidermis which, by osmosis, receive water and dissolved minerals from the soil. They are produced just behind the growing point and are short lived. **Root** pressure resulting from osmosis may be measured.

Arrangement of Tissues.—The **epidermis** is protective, the **wood** conducts water to the leaves, and the **bast** and **cortex** respectively, proteins and carbohydrates from the leaves. The **endodermis** surrounds

the **stele.** The **pith** is in the centre. **Cambium** provides for increase in thickness.

Types.—Tap root, adventitious, napiform, conical, fusiform, tuberous, prop-roots, air roots.

Chemical Constituents of plants.—Carbohydrates—starch, sugar, cellulose, inulin; proteins. Plants contain the elements C, O, H, N, S, phosphorus, potassium, calcium, magnesium iron, silicon, and chlorine—all, except carbon, obtained from the soil.

Soil contains minerals, humus, water, bacteria and air.

Mechanical analysis may be made by means of sieves to separate the soil grains into groups according to their size.

Classification.—**Sandy** soil $\frac{3}{4}$ sand; **Clay** soil $\frac{3}{4}$ clay; **Loam,** half sand and half clay; **Calcareous** soil, $\frac{1}{4}$ limestone; **Peat,** excessive humus.

Root-acid is chiefly carbonic acid formed by the carbon dioxide of respiration uniting with water. Other acids are also present. These acids dissolve minerals.

Soil water may be gravitational, capillary or hygroscopic.

Nitrogen.—Green plants get N from the soil as **nitrates** derived from humus. The bean family is assisted by **bacteria.** **Parasites** get it from the host, and **Carnivorous** plants by digesting animals. **Water cultures** show the relative importance of the different plant foods.

QUESTIONS ON CHAPTER III.

1. State what you consider the twelve chief facts about roots.
2. Compare the roots of a grass with the root of a seedling tree.
3. Define tap-root, adventitious roots.

4. What are surface-feeders, deep-feeders? How are the two classes able to live together in a forest?
5. What is meristem? How do plants grow?
6. How would you show the region of elongation in root and stem?
7. What are tropisms? What are the chief factors governing the tropisms of roots?
8. Compare the tropisms of the root with those of the stem.
9. How do water, gravity, and light affect the direction of root growth? What is the clinostat?
10. What is the use of the root-cap?
11. What is the advantage of root-hairs to a plant, and what is the advantage of their clinging so closely to the soil-grains?
12. What gas is formed by the roots? What is root acid, and what is its use?
13. Make drawings showing the different types of roots.
14. For what purposes other than food-absorption may roots be used? Give examples and make drawings.
15. In what forms are the reserves of food accumulated in roots? What purpose is served by these reserves?
16. Describe the internal structure of a root. How do branch roots arise?
17. How do green plants obtain nitrogen?
18. What are the essential foods obtained by a plant from the soil? What experiments would you make in illustration?
19. What advantage is it to a plant that the root responds to the stimulus due to moisture more readily than to that due to gravity?
20. How is the direction of a root's growth affected by light? How does a shoot differ from a root in this respect?
21. How is the growth of a root-tip affected by contact with a hard obstacle?
22. Mention some of the ways in which weeds are injurious to crops.
23. Show how such gardening operations as digging, manuring, raking, transplanting, and watering may be best carried out to minister to the needs of the plant.
24. What is "water-culture"? Give a list of the substances used in making up a culture-solution for a green plant.

25. In what region of the root does the greatest elongation occur? How may it be proved that the curvatures in response to stimuli (gravity, light, moisture, contact) also occur in this part?
26. How do root hairs absorb water? Describe one experiment in illustration.
27. Under what conditions will root-hairs be most and under what conditions least abundantly developed?
28. What is root-pressure? How is it set up, and how can it be demonstrated and roughly measured?
29. What peculiarity may be noted in the roots of the sweet pea and other plants of the same family?
30. What are the commonest nitrogenous manures?
31. Recent research shows that chlorophyll contains C.O.H.N. and magnesium. Indicate the source from which, the form in which, and the organ through which the plant obtains each of these elements.
32. What elements constitute the substance of a green plant? Through what organs, from what source, and in what form is each of these elements absorbed?
33. How is the root-cap formed? Why does it not lengthen indefinitely?
34. Why is the growing-point of the root protected by a cap while that of the stem is not so protected?
35. What structures protect the growing-point of the stem? What need is there for such protection?
36. What is a growing-point? Compare fully the growing points of root and stem.
37. Give the derivation of and meaning of the term "geotropism." What is the cause of geotropic phenomena?
38. Give one example of a plant in which some of the roots are negatively geotropic. Explain how this peculiarity serves to adapt the plant to its environment. Suggest circumstances under which the stem might become positively geotropic.
39. What relation exists between the positive geotropy of the root and the plant's need for water?
40. Which exerts the stronger pull on the root, water or gravity? Describe experiments that will illustrate your answer, and explain the advantage derived by the plant from the behaviour of its root when attracted in different directions by water and gravity respectively.

Chapter IV.

THE STEM.

The stem is, broadly speaking, a subsidiary organ of the plant, and serves rather to place other organs in positions in which they can best do their work than to perform a special function of its own. It forms an avenue of communication between the leaves and all other parts of the plant, and at the same time serves to spread out the leaves in the air and sunshine, and to display the flowers and fruit for the attraction of insects, birds and other animals.

Arrangement of Tissues.

In order to see exactly how the stem is able to act as a conducting channel it will be well to examine its structure. Cut sections of the bean stem (Fig. 56) as was done in the case of the root, being careful as before to keep both razor and material thoroughly wet. Place the sections on a piece of glass and hold them up to the light. With a good hand lens the cellular structure may be noted, though, of course, details will not be clear. The arrangement of the different tissues is, however, plainly exhibited. Inside the **epidermis,** whose presence may best be shown by tearing it from a piece of stem, is the **cortex,** in its outer parts containing chlorophyll, and therefore helping the leaves in their work. Inside the cortex is a circle of dark patches practically bisected by a complete ring of pale-coloured tissue. The dark patches are the **vascular bundles,** and the pale tissue is the **cambium**. In each bundle, the part inside the cambium ring forms the **wood** while that on the outside constitutes the **bast.** The tissue between the vascular bundles forms the

STEM STRUCTURE

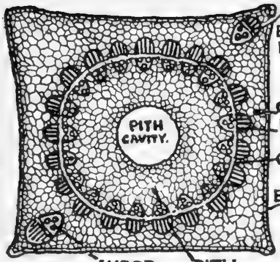


FIG.56 SECTION OF BEAN STEM

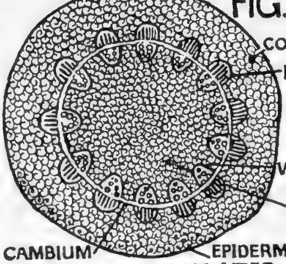


FIG.57 ONE YEAR OLD DICOTYLEDONOUS STEM

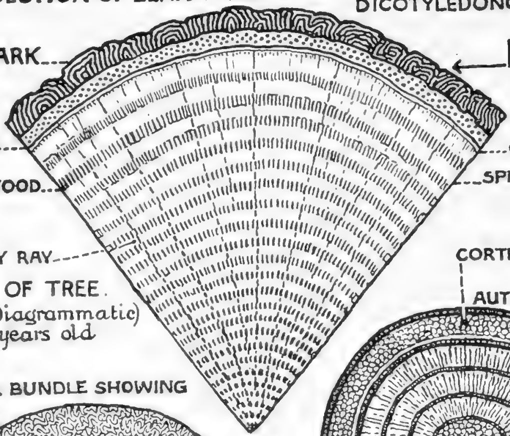


FIG.59 SECTION OF TREE STEM (Diagrammatic) About 23 years old

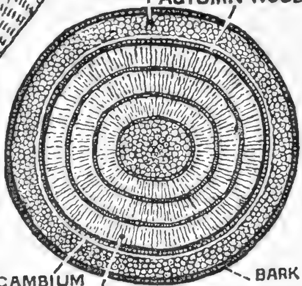


FIG.58 THREE YEAR OLD STEM OF DICOTYLEDON

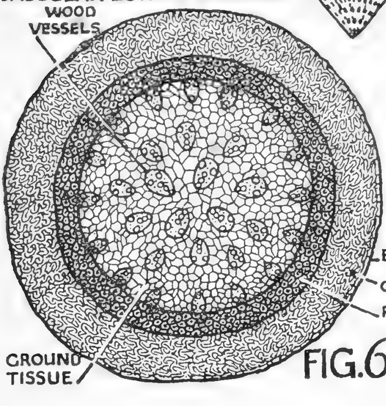


FIG.60 (Diagrammatic) SECTION OF LILY STEM

medullary rays, while that in contact with their inner side is known as **pith.** The pith cavity seen in the bean stem is absent from most plants (Fig. 57). In each of two opposite corners of the bean stem there is an extra vascular bundle. These form the leaf traces and give off vascular strands to the leaves.

Functions.—The epidermis, in the case of the stem, is purely protective. The wood, it has been seen, by means of its long tubes or vessels, conducts, from the soil, water containing dissolved minerals. In this connection it is instructive to place a number of bean plants with their roots dipping into eosin, and, by taking sections from time to time, to note the rate at which the solution travels. The bast and cortex carry respectively the proteins and carbohydrates formed in the leaves to the parts that require them, and the cambium provides for the thickening of the stem. Cells cut off from the outside of the cambium are pushed outwards to form bast, while cells cut from the inside develop to form the wood. By means of their cambium, too, the medullary rays keep pace with the development of the bundles.

The bean is an annual, so that it is not possible to trace the development of the stem from year to year. In the older stems of trees and other perennials certain new points must be noted (Figs. 58-59). The wood which now comprises nearly the whole stem is arranged in rings, each ring representing one year's growth. This ringed formation arises from the variation in growth due to the changing of the seasons. The wood produced in spring shows large and well-formed vessels, while that which originates in the autumn contains smaller vessels with much thickened walls. The **autumn wood** is therefore more compact, and thus, by its regular alternation with the **spring wood** marks out in rings the annual layers. The pith, as a rule, entirely disappears, while the cortex and bast are

cramped to the outside of the stem to form the so-called inner bark. The corky outer bark, which, as it were, replaces and takes up the work of the epidermis, is formed from the outside layer of the cortex. On removing the inner bark, the white, glistening, juicy layer of the cambium may be seen. If, in a growing tree, a thin piece of metal be slipped between the cambium and the wood it will in the course of a year be found to be covered with a layer of wood which the cambium has produced.

Now cut sections from the stem of a **monocotyledon** (Fig. 60). The flower stalk of a lily, being quite typical, is convenient for the purpose. As in the dicotyledon, there are epidermis and cortex, of which the former may again be skinned off. The cortex contains a considerable amount of chlorophyll and is therefore concerned in nutrition. At this point the resemblance between monocotyledon and dicotyledon ceases. Inside the cortex, the former shows a well-marked **pericycle**, consisting of a dense ring of strong fibres which constitute the strengthening and supporting tissue of the plant. Enclosed by the pericycle and sometimes encroaching upon it, are the vascular bundles set in a colourless **ground tissue** not unlike the pith of a dicotyledon. The bundles are not arranged in a ring, but scattered throughout the ground tissue.

No cambium is present, so that, when once the cells and vessels that constitute the bundles have reached their full size, there is no chance of further enlargement of the bundle itself.

Types of Stems.

Scientifically, the best classification of stems is, according to structure, into dicotyledons and monocotyledons, but, unfortunately, if we pursue this line we shall be forced to consider numerous microscopic differences that are beyond our scope. To classify

stems as round, like the oak and pine, square, like the bean and mint, triangular like most sedges, and ribbed like the lancewood, does not achieve much.

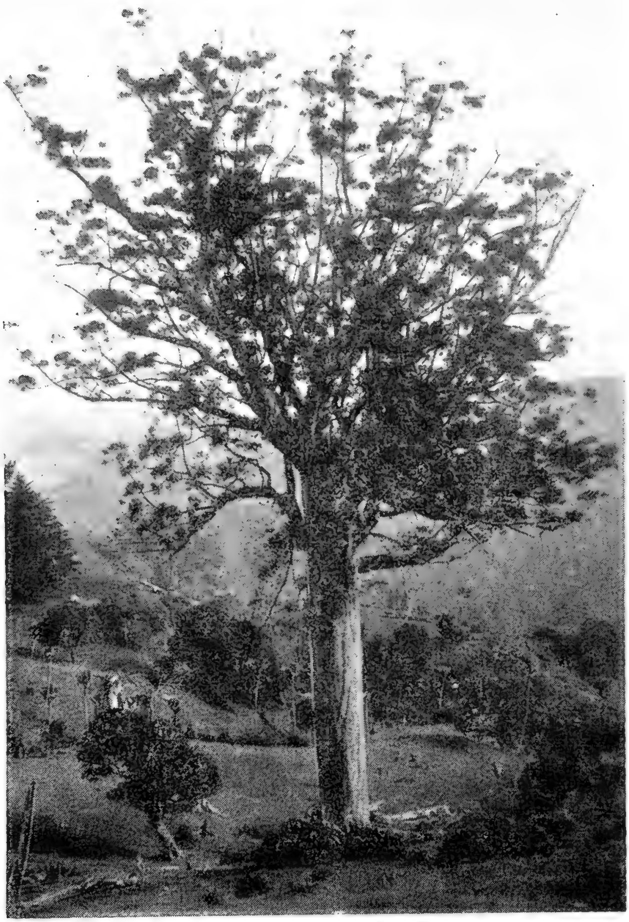
The division into annuals, enduring only for one year, biennials lasting for two years, and perennials lasting for more than two years, is good as far as it goes, but refers to the plant as a whole rather than to the stem exclusively. Then again we may distinguish herbs, shrubs and trees: herbs, soft and succulent in all their parts, shrubs, woody, but only a few feet in height, and trees, also woody, but growing to a great height and not generally branching near the ground. It is obvious, seeing that the chief distinction between shrubs and trees is merely one of size, that it is sometimes difficult to know in which class to place a particular plant.

Probably the most convenient way of classifying stems is to place in one class those that are above, and in another those that underground. The former, which we shall call **aërial stems,** may be divided into three groups—erect, climbing, and prostrate.

Erect stems are the commonest of all, for an upright branching stem is, under ordinary circumstances, the best means of displaying leaves, flowers and fruit. Such stems we see on every hand, in parks, forests and orchards, and though all are solving for themselves the same problem of securing for their leaves the maximum of light and air, yet no two are alike.

We have the *pinus insignis* and the young kauri with their straight tapering trunks and cone-shaped crowns, the puriri and the oak with branched and spreading tops, the willow with its pendent branches hanging nearly to the ground, the poplar, spindle shaped, compact in form with branches pressed close to the central stem, and the pohutukawa with contorted branches reaching out over the water from the face of some high cliff. The characteristic form of the mature

kauri is well shown in the photograph. It is clear that trees with the spreading habit are suited best to open



Kauri. *T. L. Lancaster, B.Sc., photo*

places, while those erect and sparingly branched will naturally distance all competitors in the race for light

and air that goes on in the crowded forest. In the **struggle for existence** the plants best suited to the particular environment have ousted all others, so that the survival of the fittest has been inevitably accompanied by the elimination of the unfit.

Prostrate stems, though not capable of displaying their leaves to the best advantage, are, nevertheless, suited to certain conditions. On the windswept sand dunes along the coast, erect stems would be at the mercy of every gale, and so from such places they have been ousted by creeping plants that press themselves close to the earth. There are other advantages in the prostrate habit besides that of escaping the wind. Creeping plants may root at every node, and by spreading over considerable areas derive nourishment from a large body of soil. Furthermore, if a stem be injured or the soil be blown away from some of the roots, there is always the likelihood that there will be left untouched some portion of the plant, still rooted in the soil and capable of carrying on its existence. Then, again, such plants, by covering the soil, protect it from the sun, and so reduce loss of water by evaporation. No wonder then that in such an environment they defy all competitors in the struggle for existence. The Silver Sand Grass (*Spinifex hirsutus*) a native sand-binding grass, and *Calystegia soldanella,* a New Zealand plant of the convolvulus family found on the sand dunes, are typical examples. Pennyroyal, a typical European weed, having unfortunately been introduced into the Dominion, has, with its spreading prostrate stems taken charge of the damp meadows in the neighbourhood of swamps and streams.

Climbing Stems.—It is in the forest that climbing stems are found in the greatest profusion. From year to year myriads of seeds must fall from the trees and germinate on the forest floor, and yet how rare for one to establish itself. It is impossible to produce, with

sufficient speed, a trunk that shall be self-supporting and at the same time lift its leaves to the light above. Climbing plants, by relying on others for support, and thus reducing the expenditure of material and energy necessary for the production of an independent stem, have solved the problem. They increase in length without increasing much in girth, and so, soon lift their leaves above the tops of the forest trees. Different plants have solved the problem in different ways, and it would seem that every suitable variation, whether of leaf, root, or stem, has been taken advantage of to get the leaves quickly to the light. The supplejack loops and twists itself round the branches of the trees, and when provided with suitable support, behaves not unlike the **twining stems** of the hop and convolvulus. It will be noted that, while the twining of the hop (Fig. 61) is always clockwise, that of the convolvulus (Fig. 62) and scarlet runner is always anti-clockwise. The kie-kie and several rata vines fix **aërial roots** into crevices in the bark of trees and thus pull themselves up in much the same way as the ivy. The clematis (Fig. 63) climbs by twisting its **leaf petioles** round twigs and other adjacent objects, as also does the white climbing nightshade. The New Zealand bramble or lawyer (Fig. 64), like its European relative, scrambles by means of curved **hooks** set chiefly under the petioles and along the midribs of the leaves, over the undergrowth and small trees on the verge of the forest. A curious development is seen in the eleagnus, in which the branches near the ends of the shoots bend back to form a kind of crook by which the plant may lift itself. As new branches arise nearer the tip, and those first produced are no longer needed for support, the latter straighten out and devote themselves to placing the leaves in the most favourable position for light. The passion flower, a species of which is found in the New Zealand forest, the grape vine, the sweet pea, and the

CLIMBING PLANTS

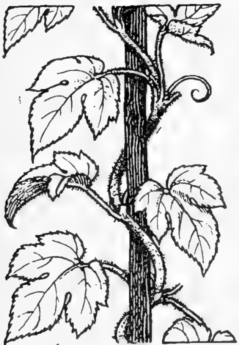


FIG. 61 HOP

FIG. 62 CONVOLVULUS

FIG. 63 CLEMATIS

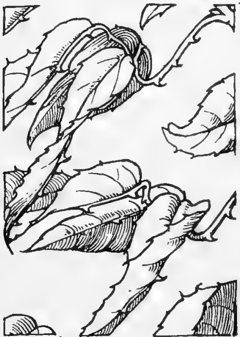


FIG. 64 BUSH-LAWYER

FIG. 65 SWEET-PEA

FIG. 66 VIRGINIAN CREEPER

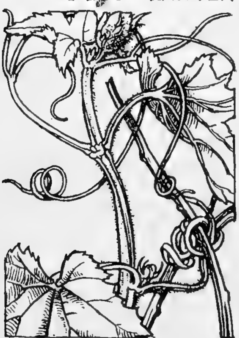


FIG. 67 CUCUMBER

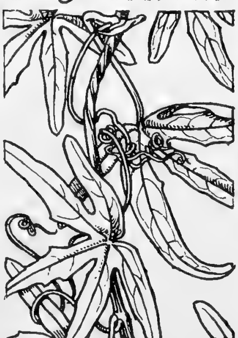
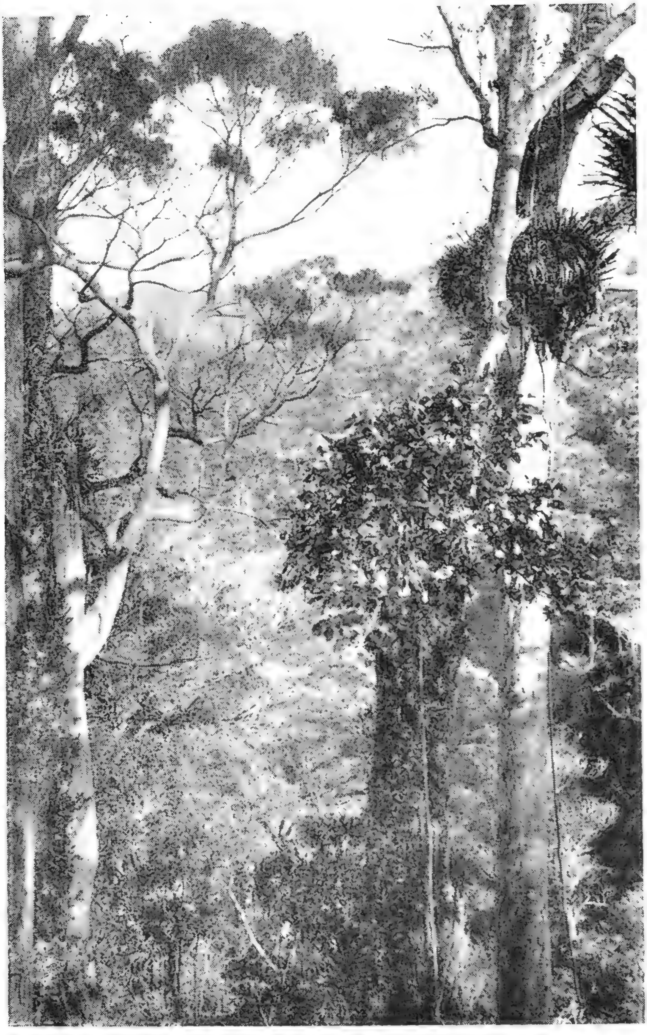


FIG. 68 PASSION FLOWER

FIG. 69 GRAPE-VINE

cucumber climb by means of **tendrils**, sensitive, coiling, wire-like modifications of various organs in which a marked irritability of the protoplasm shows itself in their response to the contact of adjacent objects. In the passion flower (Fig. 68), the tendril is a modified branch, as may be seen from the fact that it arises in the axil of a leaf; in the vine (Fig. 69) it is a modified inflorescence, indicated by the circumstance that it may on occasion bear a few flowers; in the cucumber (Fig. 67) the tendrils are adapted from the stipules, while in the pea (Fig. 65) they are formed from the midribs of leaflets that have lost their flat green blades. The Virginia creeper (Fig. 66) climbs by its branching tendrils which are produced like leaves. At the tip of each tendril-branch is formed a disc-like sucker that attaches the plant to walls and other flat objects. Tendrils are highly sensitive, and respond to the contact of a swinging object less than an eighth of the weight of the lightest object that can be felt by the most sensitive part of the human skin. With all twiners, as well as leaf and tendril climbers, the process is the same. The development of the side that is touched is checked, while development continues on the side remote from the object with which the tendril is in contact. This causes the organ to curve spirally round the support till it is firmly fastened to it.

Epiphytes are here mentioned in order that they may not be confused with climbers. Epiphytes are plants that grow on other plants. They differ from **parasites** in not penetrating with their roots the tissues of the plant on which they live. While parasites send their roots into and live on the sap of the host, epiphytes gain their food materials from the decomposing bark, dust, and other substances that have fallen in the fork or stuck to the trunk of the tree on which they live. Thus the mistletoe, which, in its season,



T. L. Lancaster, photo

Note the broadleaf growing as an epiphyte on the middle tree and throwing down a slender root to the soil.

makes the beech forests of the South a blaze of scarlet, is a parasite, while the Northern rata often germinates and begins life as an epiphyte high up in the fork of

a tree. The broadleaf and astelia, as well as the earina and dendrobium, common New Zealand orchids, are also epiphytes. In the photograph reproduced on the preceding page a broadleaf is shown growing on a rata and throwing down a root towards the earth, while in that on the next page a rata is seen doing the same thing, but on a larger scale.

A stolon is a branch that roots at the tip. It is often seen in the gooseberry, and is the chief means by which grasses like fiorin are able to spread. By **layering**, artificially formed stolons are made to produce new plants. The branch to be layered is pinned to the earth at one of its nodes and there produces roots which, when thoroughly established, permit the branch to be severed from its parent.

A **runner** (Fig. 70) is a long slender branch that roots at the tip and there produces a tuft of leaves. The strawberry and violet are propagated by runners.

An offset is a short, stout runner that roots close to the parent plant. The echeveria, a common border plant, is propagated by this means.

A **sucker** is an aërial shoot that rises from an underground stem or even from a root. In the mint, suckers spring from a rhizome, but in the poplar more frequently from the root.

Underground stems have been diverted from the work of spreading out the leaves which may be regarded as a true stem-function, and have more or less confined themselves to the storing of reserve material to meet the requirements of the plant or its offspring. They may be distinguished from roots by the presence of leaf-buds.

A **rhizome** (Fig. 71) is a horizontal underground stem that gives off leaves above and roots below, though in some cases, as in the supplejack and Solomon's Seal, it may produce aërial shoots as well. It is well seen in the bracken fern, the New Zealand

T. L. Lancaster, B.Sc., photo

Thick aërial roots descending to the earth from rata epiphytic on rimu. Note finger-like branch-roots gripping the trunk.

flax (*Phormium*), and the iris. In rhizome plants, the leaf petioles are usually long, and, by lifting up the leaf blades to receive the light, do the work

omitted by the stem. Many grasses, like the bamboo and couch grass, have the rhizome habit and are, for that reason, hard to eradicate. Their subterranean stems push their way through the soil, but little hindered by the presence of other plants, and, branching from time to time, soon spread over large areas. This is why rhizome plants, in the struggle for existence, are able to starve out most others.

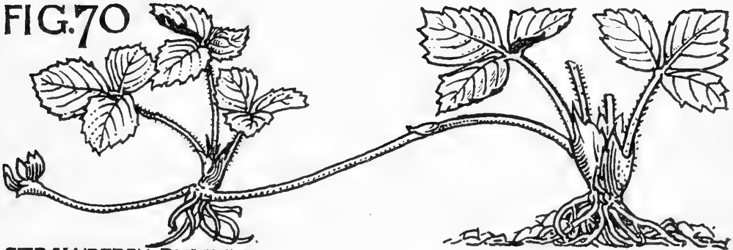
The tuber (Fig. 72) is a swollen portion of an underground stem, of which the potato is the common example. The eyes are the embryo branches and are situated at the nodes, lying in the axils of extremely small scale-like leaves. These scale leaves are much more distinct in the Jerusalem artichoke, another common garden tuber.

A **bulb** consists of a short conical stem surrounded by the fleshy bases of leaves which contain the food reserves. There are two types of bulb, the **tunicated** (Fig. 73), in which the leaves completely sheathe the stem, and the **scaly** bulb (Fig. 74), in which the fleshy scale-like bases do not sheathe, but are arranged in a spiral on the conical axis. The onion and lily are respectively familiar examples of tunicated and scaly bulbs. In the spring, the conical axis lengthens into the flowering stem, and some of the leaves appear above ground and become green. At first, the chief nutriment is drawn from the fleshy leaf bases, but when chlorophyll is developed, carbon is taken from the air and used, not only to supply the growing shoot, but to form fresh reserves for next year's stem. Young bulbs develop in the axils of the fleshy leaves and provide for vegetative reproduction.

A **corm** (Fig. 75), well seen in the gladiolus and crocus, is a short, fleshy, thickened stem covered by membranous leaves. At the top, alongside the remains of last year's flowering stem, and hidden by the leaf scales, is the young shoot which will, in due season,

STEM MODIFICATIONS

FIG. 70



STRAWBERRY·RUNNER

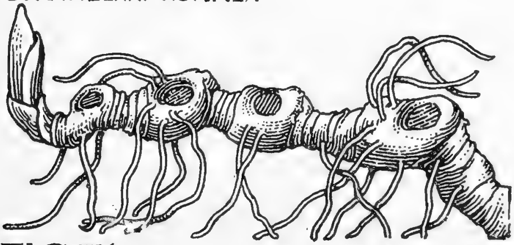


FIG. 71 RHIZOME·OF·SOLOMON'S·SEAL

CROCUS CORM

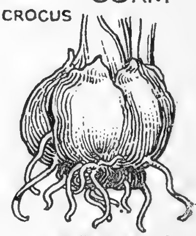


FIG. 75

ONION·BULB TUNICATED

FIG. 73

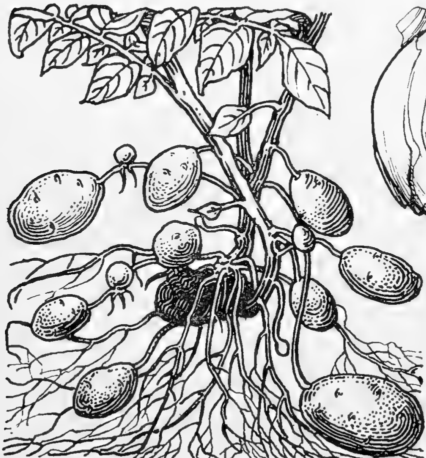
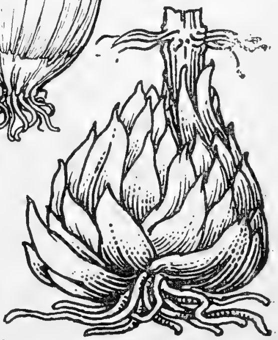


FIG. 72 TUBER·OF·POTATO



SCALY·BULB·OF·LILY FIG. 74

grow up into the light and bear the flowers. As this grows, using the reserves by which it is surrounded, it produces at its base a swelling which forms the next season's corm. The exhausted corm of the previous season is always to be found below the one that bears the flower. In the corm, too, young corms are found as buds in the leaf axils, and vegetatively produce new plants.

Stools are formed in the canna. These consist of the fleshy roots together with the bases of the stem. By splitting the stool of a canna new individuals may be obtained.

Vegetative reproduction, we have seen, may be brought about in various ways: by division of rhizomes, stools, and tubers; by severing from the parent plant stolons, runners, off-sets and suckers; by breaking off the buds of bulbs and corms. Many plants, too, are propagated by cuttings. Thus slips are cut from the branches of geraniums, currants, and roses, and these, placed in the ground, produce roots from the nodes and establish themselves as independent plants.

Buds.

A bud is an undeveloped branch, in which the nodes are crowded together in such a way that the young leaves overlap and protect the growing point. When such buds are produced in the axils of the leaves they are termed **axillary**, and when at the tip of the stem or branch they are called **terminal.** **Adventitious** buds may, under special circumstances, spring from any part of the plant that produces them. When a willow tree is lopped, the stem at once sends forth a number of adventitious buds that produce a tufted crown of new branches. Where plants have been badly whipped by the wind, or have had their leaves destroyed by insect or fungoid pests, this power of producing new buds clearly gives them a great advantage in the struggle

for existence over others not possessing it in the same degree. Begonias are often propagated by buds produced on their leaves. The leaf is sliced and fixed to the damp earth of the pot, when the edges of the cut produce buds and roots that give rise to new plants. In the poplar, as has been remarked, such buds may form suckers from the root. Some trees, like the walnut, produce **accessory** buds in the axils of their leaves. Usually only the chief or central bud matures, but, if anything happens to this, one of the accessory buds develops to take its place. This is nature's provision against loss through wind, frost, or other cause. The buds of many trees are, in winter, covered with leathery **bud scales,** and even in some cases with a gummy or resinous coat which protects the tender leaves and growing point against cold and drought; for, in winter, when the leaves have fallen, water does not pass freely from the soil. Such scales are found on the ash and other trees, while in the willow they are replaced by a dense growth of hairs.

After the leaves have fallen in autumn, the buds remain dormant throughout the winter; but, when spring has come, the scales fall off, and, beginning at the base, the leaves unfold. At the same time the internodes lengthen, and, in the axil of each tender leaf, a new bud appears, in its turn to lie dormant through the winter, and develop in the spring.

Before leaving this subject we must note that all buds do not develop into leafy shoots. Some are **flower buds** and produce, instead, flowers, which, after all, are themselves but branches clothed with groups of leaves that have been specially arranged and modified for reproduction.

Budding and Grafting are horticultural operations by which, in one case, a bud, and in the other, a twig called the scion, taken from a plant it is desired to propagate, is fixed to and made to unite with a stock

or stem that has its roots established in the ground. The important thing in both cases is to have the cambium layer of bud or scion in contact with that of the stock and to exclude all air carefully from the point of junction. By this means new plants exactly like that which produced the bud or scion may be obtained, in which respect vegetative differs from seed reproduction. In the latter, for instance, seedlings raised from stones derived from the choicest peaches and cherries may give rise to but worthless varieties.

Roots and Stems.

Both roots and stems have epidermis, cortex and stele. In roots, the growing point is protected by a root-cap, in stems by a sheath of leaves. In roots, wood and bast are separate, being arranged alternately; in stems they are united in vascular bundles. Stems have nodes and internodes, and roots have not. Root branches originate from the stele, while stem branches spring from the cortex. Roots are, as a rule, positively geotropic and hydrotropic, and negatively heliotropic, while stems are positively heliotropic and negatively geotropic and hydrotropic. Stems bear leaf buds, while roots, as a rule, do not. Root hairs, too, are an entirely different thing, and perform a different work, from the hairs of stems and leaves.

Reserve Materials.

Reserve materials are always found in seeds, but in some plants they accumulate also in the stems, roots or leaves. Since the topic has already been, and will again be discussed, it may be well to give a brief summary, and this summary, if all tests be duly made, will give all the assistance required. It may be mentioned as a preliminary, that, in testing for starch and sugar, it is best to add the iodine first. Then, whether starch is present or not, the Fehling's solution may be

added to the same material and the test proceeded with in the usual way.

In **seeds** the reserves are to support the seedling till it can gather nourishment for itself. All seeds contain **protein** to supply nitrogen, and either **carbohydrate** or **oil** to supply energy. The carbohydrate, as in the pea, bean, and all cereals, is chiefly starch, though rye contains a good deal of sugar. In the castor bean there is **oil** instead of starch. The date endosperm is **cellulose.**

In **roots,** the reserve is chiefly carbohydrate. The parsnip and kumara contain both starch and sugar, the carrot and turnip sugar only. The red beet contains cane sugar, which, differing from glucose or grape sugar, which is the form usually found in fruit and vegetables, does not at once respond to the Fehling's solution test. This is, as a rule, true only of the long-rooted beet, since the turnip-rooted variety usually contains grape, as well as cane sugar. Slice some red beet and boil it for an hour or more in water to which a few drops of strong sulphuric acid have been added. Kill the acid with carbonate of soda and then test for sugar. The usual yellow precipitate will be obtained. The cane sugar has been changed into invert sugar, which responds at once to the Fehling's solution test. The dahlia root contains the carbohydrate **inulin,** which may be precipitated with methylated spirit, and gives a yellow colour with iodine. In biennials, such as the parsnip, carrot, and turnip, the reserve is accumulated in the first year, to produce flower and fruit in the second, while in kumara and dahlia it is to support the young shoot which, in the spring, sprouts from the stool to form the new season's plant.

In modified **stems,** such as the potato tuber and various rhizomes and corms, starch is found in plenty. The potato also will, as a rule, be found to contain a

little sugar, especially when new, or when it is beginning to shoot, and soluble carbohydrates are required. In the Jerusalem artichoke, another tuber, we again find inulin, though sugar, too, is always present. The reserve material of stems is accumulated during one year to nourish the young shoot of the next.

In Leaves.—In the fleshy leaf bases of bulbs carbohydrate is present. The onion, for instance, shows a copious supply of sugar. In the onion, which is a biennial, this sugar is for the production of flower and fruit in the second year. In the bulbs of the lily and narcissus, however, the reserve merely supplies the young shoot till it can gather food for itself and return what it has borrowed from the store below.

Fruits, like the apple, cherry, and blackberry, have sugary flesh which, forming the food of birds and other animals, provides for the distribution of the seed. In cases moreover where the fruit falls naturally to the ground, the fleshy material rots and forms a supply of humus that the young seedling can use as soon as its roots are established.

Summary.

Stems conduct inorganic materials to and organic materials from the leaves, and serve to spread out the leaves and display the flower and fruit. A dicotyledon has **epidermis** to protect; **cortex** to conduct carbohydrates from the leaves; a ring of **medullary rays** alternating with **vascular bundles**, the latter consisting of **bast**, to conduct proteins from the leaves; **cambium** to provide for growth, and **wood** to conduct water from the root; **pith**, and sometimes pith cavity in the middle. In older stems **annual rings** mark the difference in growth of spring and autumn wood, pith disappears, cortex and bast form the inner bark, and the outer cortex forms corky bark. In **monocotyledons**,

epidermis and cortex are the same as in **dicotyledons**, a well-marked **pericycle** is seen, and the vascular bundles, which have no cambium, are scattered through the **ground tissue.**

Aerial Stems.—Erect stems are commonest. Prostrate stems spread over the ground and root at the nodes; climbing stems make use of support to reach the light without becoming thick; epiphytes grow on plants without penetrating their tissues; parasites penetrate and use the sap of the host; stolons, offsets, and runners are branches rooting at the tip; a sucker is a shoot rising from below ground.

Underground Stems.—A rhizome is horizontal, and gives off leaves above and roots below. A tuber is the swollen tip of an underground stem, a bulb has a conical axis enveloped in thick leaf bases—two kinds (tunicated and scaly). A corm is a short fleshy stem sheathed in membranous leaves. Stools are partly root and partly stem.

Vegetative reproduction may be by rhizomes, stools, tubers, stolons, runners, offsets, bulbs, corms, cuttings, buds, and grafts.

A bud is an undeveloped shoot usually leafy, sometimes flowering. Buds may be axillary, terminal, adventitious, accessory.

Roots and stems compared. A summary itself.

Reserve materials.—Seeds contain proteins and carbohydrates (starch, sugar, cellulose), or oil to support the seedling.

Roots may contain starch, grape sugar, cane sugar, or inulin, either to produce flower and fruit in the second year, or to support that year's shoot. **Stems** contain starch, sugar, or inulin to support the next year's shoot. **Leaves** of bulbs contain carbohydrate, in the onion to produce flower and fruit in the second year, and in others to support that year's shoot. **Fruit**

contains sugar, which is chiefly for distribution of the seed, but may form humus.

QUESTIONS ON CHAPTER IV.

1. Compare roots and stems with regard to structure, function, tropisms.
2. Give examples of herbs, shrubs, and trees. What points of likeness and difference do you note?
3. How would you distinguish the poplar, oak, willow, ash, and elm in winter time?
3. Describe the means by which plants climb. What is the advantage of the climbing habit?
4. Define tuber, bulb, corm, rhizome, stolon, sucker, runner, off-set. What is the advantage of the rhizome habit?
5. Describe the structure of an onion bulb and of a potato tuber.
6. Describe the stools of the dahlia and canna.
7. Compare one-year old, three-year-old, and ten-year-old stems of any available tree.
8. What are the advantages and disadvantages of prostrate stems? Describe any prostrate stems you know.
9. Draw sections of one-year old monocotylous and dicotylous stems. Compare the arrangement of the tissues.
10. What advantage have hollow over solid stems?
11. Describe the structure of an ordinary bud.
12. Compare spring and autumn wood.
13. In what plants are the stems eaten, and in what others do the stems yield useful substances?
14. Give a tabular classification of stems.
15. Distinguish epiphytes and parasites. What are the commonest epiphytes and parasites in New Zealand?
16. What are the functions of bast, wood, cortex, and epidermis?
17. How would you distinguish the following trees in winter: —ash, pinus insignis, plum, apple, pear, peach?
18. Name three native trees with which you are familiar. Describe their habit, branching, buds, and bark.
19. What is a growing-point? Compare the growing-points of roots and stems.

20. Describe the way in which a dicotylous stem grows in thickness, and explain how it is that the stem shows annual rings.
21. An oak stem continues to grow in thickness as long as the tree lives, but the stem of a palm does not thicken after it is once formed. Why is this?
22. Through what tissue does the water from the soil ascend the stem from root to leaf? How could you show this?
23. What is meant by the translocation current? How could you show through what tissues it travels?
24. What materials would you use for a lesson on "Stem Modifications" to a class of children between the ages of 11 and 13?
25. What is bark, and what purpose does it serve?
26. What are bud-scales? How could you hasten the opening of buds? What risk is involved in doing this?
27. What are adventitious buds? Under what conditions do dormant buds become active?
28. What is the difference between a flower bud and a vegetative bud? Explain the relation that exists between them.
29. In what parts of plants, in what forms, and for what purposes are reserves of food accumulated? What changes must certain of these reserves undergo in order to become available?
30. Describe the different ways in which a plant may produce vegetatively.
31. Draw a vertical section of an ordinary bud. Show clearly the arching leaves and indicate the position of the growing point.
32. What important precautions must be taken in the operations of budding and grafting? Can you suggest any reasons why these precautions should be necessary?
33. Compare roots and stems, dealing with structure, tropisms, appendages, and mode of growth.
34. What are the tests for starch, grape sugar, inulin, cellulose, oil, solid protein? In what parts of plants would you expect to find each of these substances respectively?
35. Explain fully the advantages and disadvantages possessed by climbing stems. Classify the different methods by which plants climb.
36. What types of plant succeed best on the wind-swept sand dunes? Give reasons.

Chapter V.

THE LEAF.

As the root is concerned with the soil, so the leaf is concerned with the air and sunlight. It is to these elements in its environment that the leaf relates the plant. It is by means of the leaf that the plant receives carbon dioxide from the air and uses the energy of the sunlight, first to decompose the gas and then to build its carbon with materials from the soil into the organic compounds the plant requires.

That the leaf is the light-related organ of the plant is naturally suggested by the fact that, under whatever circumstances the individual may be growing, it usually develops in such a way as to secure for its leaves collectively the greatest possible illumination. The leaves, we find, lie more or less **horizontally**, obviously the best position for receiving the sunlight. When, however, plants are grown where light is received only on one side, as is the case with window plants, the stems turn to face the light, so that the flat surfaces of the leaves are exposed to the rays.

Leaves, again, are generally arranged on stems in **vertical rows,** so that the light may reach them all by means of the avenues between.

As a rule, the narrower the leaves, the greater the number of rows, so that the avenues may not occupy an undue proportion of the space. This brings us to the question of **phyllotaxis** (Gk. *phyllon* a leaf and *taxis* arrangement) by which we mean the arrangement of the leaves on the stem. In the tea-tree, for instance, there are five rows, in the veronica (*koromiko*) there are four; while in grasses, as may be well seen in the bamboo, there are only two. In the veronica, the leaves are set in opposite pairs, each pair being at

right angles to that immediately above and below it. This arrangement is called **decussate.** Where leaves are placed in a ring round the stem, as in cleavers, the arrangement is said to be **whorled,** and where neither whorled nor opposite it is **alternate.**

Compare the number of rows of leaves on a willow branch with that on the stem of a tobacco plant. These two plants will illustrate another principle concerned with shade prevention. Where the leaves are long, as in the tobacco, the internodes of the stem are also long so that there shall be no overlapping, whereas short leaves, as in the willow, are set at short intervals.

By an adjustment in the length of the leaf **petioles,** shading may be avoided. The petioles of the lowest leaves are often long, carrying them outside the shade of the foliage on the upper part of the stem. A similar arrangement is seen in many rosette plants such as the dandelion and cat'sear (Fig. 78). In other cases the lowest leaves grow outwards horizontally from the stem while those above grow more vertically. This is the case with the buttercup. The leaves springing from the base (the radical leaves) have long petioles and spread horizontally. Shading of these is prevented in two ways: by the reduction in size of the upper leaves, and by the fact that these latter spring more vertically from the stem. The woolly mullein furnishes an even better example.

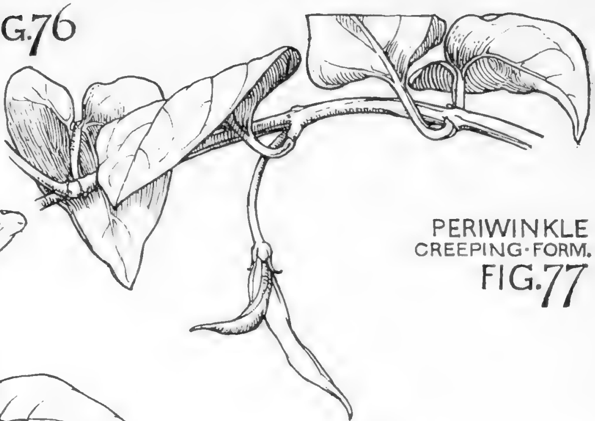
In the case of **compound** leaves (*i.e.*, leaves, in which, like the bean, the blade is divided into several parts) there is not generally reduction of the upper leaves or lengthening of the lower petioles, since, at some time or other during the day, the sunlight is able to make its way through the broken blades as they move to and fro in the breeze.

In **creeping** stems, as a rule, every leaf assumes the horizontal position. In the periwinkle (Figs. 76-77) for instance, the arrangement of the leaves is,

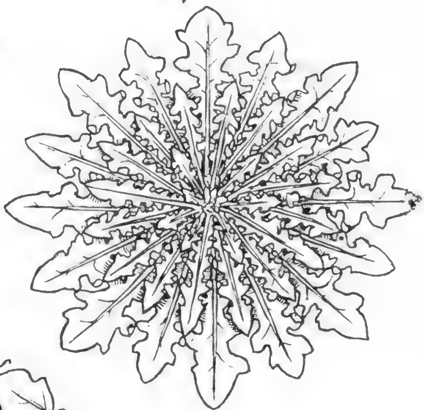
ARRANGEMENT OF LEAVES

FIG. 76

PERIWINKLE.
UPRIGHT·FORM.

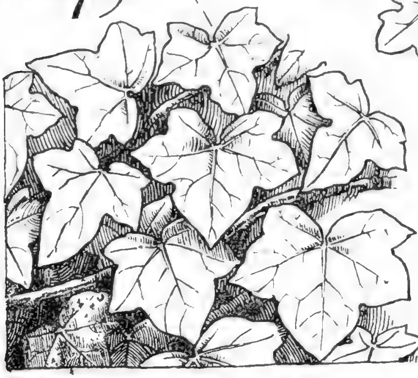


PERIWINKLE
CREEPING·FORM.
FIG. 77



CAT'SEAR·ROSETTE
FIG. 78

FIG. 79



LEAF·MOSAIC·OF·IVY.

properly speaking, decussate, and so appears in upright shoots; but in creeping shoots all the leaves are brought into the same plane by the twisting of every alternate internode. In this way the best possible illumination is secured.

Everywhere may be seen **leaf mosaics** (Fig. 79) or groups of leaves so arranged that they receive collectively the maximum illumination possible, or, in other words, so placed that they throw the least possible shade on one another.

A normal plant produces the largest leaf surface that can be adequately illuminated, and so makes the best possible use of the space at its disposal. This accumulation of evidence strongly indicates that there is a close relation between the leaf and the light.

STRUCTURE.

The external characters of the leaf have already been examined. The stalk or petiole holds it out from the stem, while the blade, by means of its chlorophyll, builds the organic from the inorganic. The midrib and veins are continuations of the vascular bundles, that, passing from the root, traverse the stem and branch to form a network that takes to every part of the leaf blade the raw materials from the soil.

It will now be advisable to get some idea of the arrangement of the tissues. Between the thumb and forefinger of each hand hold a broad bean leaflet by its ends, with the lower surface towards you. Now tear it diagonally across. It will be found that a colourless membrane, thinner than the thinnest tissue paper, is here and there removed. This is the **lower epidermis.** On attempting to remove the **upper epidermis** in the same way it will be found that a certain amount of the green tissue from the interior comes away with it. Where both upper and lower epidermis have been removed it will be seen that between

these is a layer of green spongy material, the **mesophyll** (Gk. *mesos* in the middle and *phyllon* a leaf), which is traversed by the veins. Another good way of separating the tissues is to boil for ten or fifteen minutes in caustic soda some small firm leaves that have un-notched edges, as, for instance, those of the box and privet. Holding one of these under water cut off a strip round the edge and then, with a pair of needles mounted on wooden handles, separate it into upper and lower epidermis and mesophyll.

To examine further into leaf structure demands the use of the microscope and an ability to cut sections such as could not reasonably be expected of the students who will use this book. So important, however, is this matter, and so closely related is structure to function, that detailed drawings are supplied. For those who have the time and patience to acquire the necessary manual dexterity, and possess a microscope to examine its result, the following instructions will prove useful. Roll a bean leaflet into a firm coil, and, holding it lightly so as not to crush the tissue, cut the top off the coil in order to obtain a flat surface. Now, using a very sharp razor, and being careful to keep both razor and coil quite wet, slide the blade over the flat surface without trying to cut anything. Sections may in this way be obtained, as it were by accident. With a camel's hair brush remove these to a glass slide, mount in water, and examine under both low and high powers. In preparing for examination the epidermis that has been peeled off no such difficulty is encountered. It is merely mounted in water, flat on the slide.

In the leaf sections (Fig. 80) it will be noted that the outside walls of the cells of the upper epidermis are thicker than in those of the lower, as might be expected from the necessity for greater protection in the more exposed position. In the lower surface, and

to a less degree in the upper, appear small openings, the **stomata,** through which the leaf receives air and gives out oxygen and water. The whole structure of the leaf is admirably adapted for the ingress and egress of atmospheric gases. In the loose spongy tissue that forms the lower part of the mesophyll there are large spaces communicating, through the stomata, with the air outside. The more compact upper part of the mesophyll is **palisade** tissue consisting of elongated cells, which by their arrangement are able, when necessary, to protect the chlorophyll from the effects of too strong light. All the cells of the mesophyll as well as the guard cells, which form the entrance to the stomata, contain chlorophyll. This may be dissolved out by methylated spirit or other alcohol, in which case a green solution is obtained and the leaf becomes colourless.

The stomata (Fig. 81) are so numerous that, by diffusion, they admit air to the mesophyll as freely as if there were no epidermis present. This air comes into contact with the walls of the interior cells, the protoplasm of which, exerting its selective influence, permits the carbon dioxide alone to pass through. Inside the cell, then, we have the chlorophyll, which can absorb and utilise the energy of the sunlight, the carbon dioxide which has penetrated from the air, and the water and dissolved mineral salts brought from the soil. It will now be necessary to consider the processes that are collectively known as photosynthesis.

Photosynthesis.

Photosynthesis (Gk. *photos* light and *synthesis* a putting together) or carbon-assimilation, as it is sometimes called, is a process that comprises at least two stages. In the first place the protoplasm of the mesophyll cells, employing the energy of the sunlight absorbed by the chlorophyll, decomposes the carbon

LEAF STRUCTURE

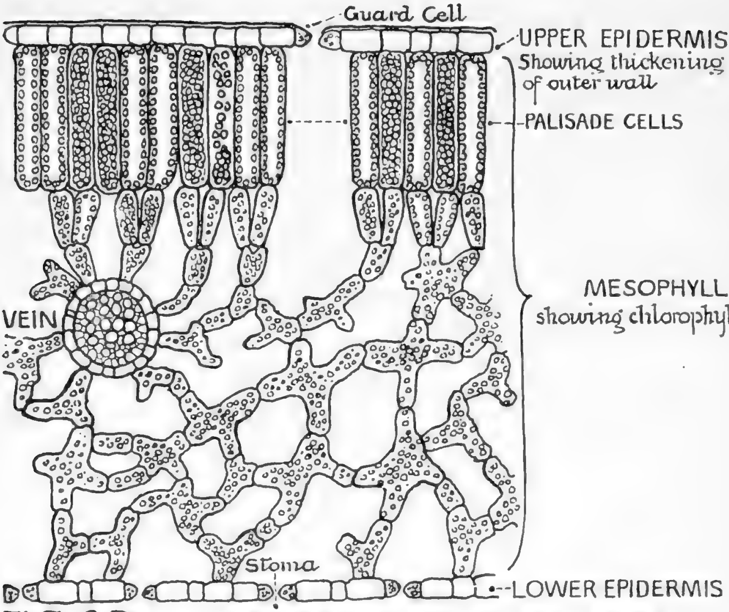


FIG. 80 SECTION OF BEAN LEAF

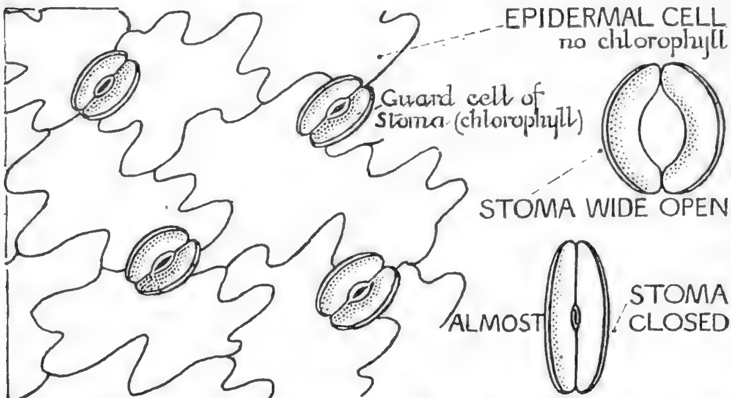


FIG. 81 EPIDERMIS OF BEAN LEAF STOMATA

dioxide that has entered from the atmosphere into its elements carbon and oxygen, of which the oxygen alone is restored to the air. The second stage is the building up (*synthesis*) of the carbon with the elements of water to form a carbohydrate. The carbohydrate first formed is doubtless some variety of sugar. Now, since sugar is soluble, it is quite clear that any considerable quantity of that substance would reduce the cell sap to a viscid treacly mass, quite unsuited for circulation. Therefore, during the day, when the leaf is most active, the elements necessary to form a certain amount of water are taken away from the sugar, by which means that substance is converted into starch. The insoluble starch is temporarily stored in little granules which do not impede the flow of the sap. The sugar, however, that the plant can use immediately, retains its original soluble form. So much for the production of carbohydrates. The formation of proteins must now be considered. It would appear (though this is by no means certain) that some of the sugar in the cells of the mesophyll acts on the nitrate of potash brought from the soil in such a way as to throw out the potash and form **amides,** soluble nitrogenous compounds consisting of carbon, oxygen, hydrogen, and nitrogen. Since experiment has shown that both chlorophyll and sunlight are necessary for the formation of amides, it would seem that such formation is a branch of photosynthesis.

At all times, the sugar and amides make their way to the parts that require them, and are dealt with there by the protoplasm in such a manner as to form the living tissue of the plant or add to the accumulation of reserves. The sugar may form celluose, starch or inulin, while the amides, with the addition of phosphorus and sulphur brought from the soil, are converted into proteins as well as the living protoplasm that lines the cells. During the day, there is formed

more carbohydrate than the plant can deal with, so that, as we have seen, this is temporarily stored up in the form of starch. At night, it is on this temporary store that the plant draws, not only to build its substance, but to supply, by oxidation, the energy required for its vital processes. Therefore, during darkness, the starch is re-converted into sugar, so that, after the light has been excluded from the plant for some time, starch will be found to have disappeared from the leaves.

Definite experiments relating to the formation and storage of starch may easily be made.

Certain **minerals** appear to be necessary. We found by water cultures that plants grown without potash were more or less stunted, and further investigation shows that this is chiefly owing to the fact that without **potash** photosynthesis does not take place. Then again, though **iron** does not enter into the composition of chlorophyll, yet chlorophyll is not formed in its absence, and since, without chlorophyll, there is no photosynthesis, iron is essential to this process.

The absence of chlorophyll is obvious to the eye, but the fact that starch is not being formed must be proved in a way that will be indicated in connection with the next experiment.

To show that **light** is needed for photosynthesis, partly cover with some opaque substance leaves that are growing in the bright sunlight. To do this, obtain a small flat stand, (a block of wood will do), lay on this a piece of soft loose felt that will allow air to pass freely between its fibres, and then, without detaching the leaf from the plant, lay its blade on the felt, and cover part of it as directed. A good plan is to place a stencil on the leaf, so that the light reaches the surface only where the pattern is cut (Fig. 82). The leaf should then be left till the

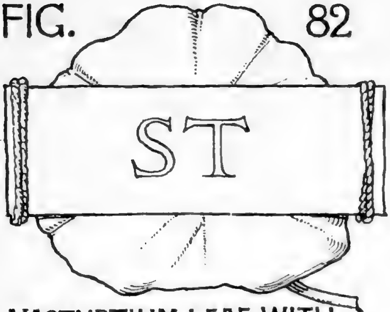
following day and picked about the middle of the afternoon. It should now be placed in boiling water for a minute or two, for the purpose not only of expelling the air it contains, but of killing its protoplasm, so that there may be no further changes in its organic compounds. Thus, if starch is present, we shall be sure of finding it even if the leaf is left for a considerable time. Now place the leaf in methylated spirit and leave it for some time. If the leaf is a soft one, like those of the so-called nasturtium, it will bleach in the course of an hour or so, but if it be boiled in the spirit it will bleach at once. We now have a perfectly colourless leaf in a solution of chlorophyll. On removal from the spirit the leaf will be found to be very brittle. Lay it on a white saucer and wash it with water till it again becomes soft, and then pour iodine on it. The parts that were exposed to the sun will shortly show a blue black colour, indicating the presence of starch. Thus the pattern of the stencil is marked out on the leaf, the part that was covered remaining unaffected by the iodine. Light is therefore necessary for starch formation.

Another method is to place flat slices of cork opposite each other on either side of a growing leaf and fix them to the leaf by passing a couple of pins right through both corks and leaf (Fig. 83). While starch will be found in the exposed parts of the leaf, the portion covered by the cork will contain none. This is not so satisfactory as the previous experiment, since the corks pressed against the leaf surface hinder the access of air.

Chlorophyll is essential to photosynthesis, for it is this substance alone that can absorb and utilise the energy of the sunlight. This is easily shown. In the bright sunlight pick variegated geranium leaves (Fig. 84) and treat them as in the last experiment, noting that they take much longer to bleach than the

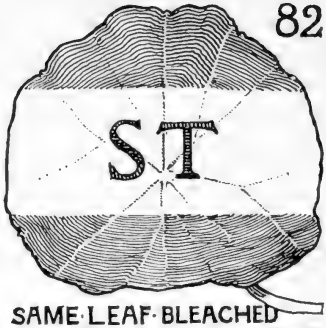
PHOTOSYNTHESIS

FIG. 82



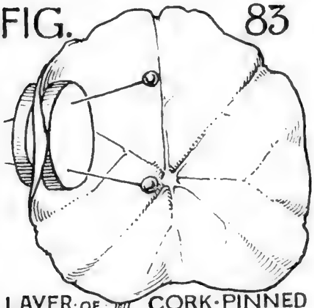
NASTURTIUM·LEAF·WITH·
STENCIL·APPLIED

82



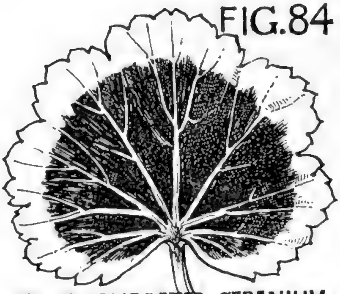
SAME·LEAF·BLEACHED
AND·TREATED·WITH·IODINE

FIG. 83



LAYER·OF CORK·PINNED
TO·UPPER· AND·LOWER·SIDE

FIG.84



LEAF·OF·VARIEGATED·GERANIUM
BLEACHED·AND·TREATED·WITH·
IODINE

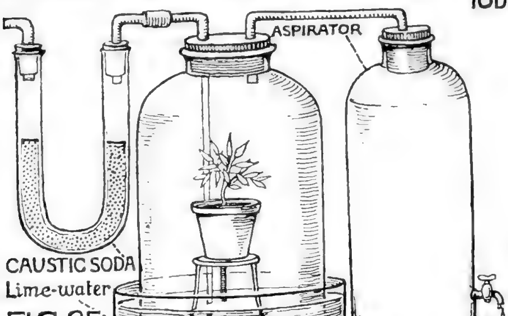
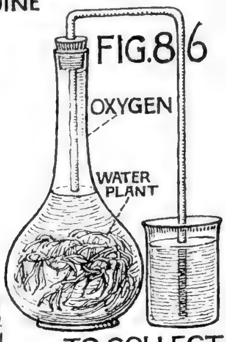


FIG.85
PLANT·GROWN·WITHOUT·
CARBON·DIOXIDE

FIG.86



TO COLLECT
OXYGEN

leaves of the nasturtium. The iodine test will show that starch is present only in parts that were green. By sketching the leaf before and after the experiment, it will be seen that the areas without chlorophyll exactly coincide with the areas without starch. Chlorophyll is essential to starch formation. This is indirectly illustrated in another way. Where a plant is grown in the dark, as for instance where a patch of grass is covered with a sack, the leaves lose all their chlorophyll, which is replaced by a yellow substance called **etiolin**. The plant is said to be etiolated. Since, owing to the absence of light, starch formation is impossible, the plant does not waste energy in forming chlorophyll.

The **carbon dioxide** that supplies the carbon comes from the air. This may be proved by keeping a plant in an atmosphere devoid of that gas. The most satisfactory way of doing this is to obtain a suitable plant growing in a pot and place it on a stand under a bell jar standing in a dish containing a little lime water. By means of an aspirator the air is drawn into the jar through a solution of caustic soda, this substance having the power to absorb carbon dioxide (Fig. 85). At the beginning of the experiment the aspirator should be filled and emptied several times, so that the air originally in the jar may be drawn out and replaced by that which has passed through the caustic soda. The lime water in the dish absorbs any carbon dioxide given off by the respiration of the plant. During the day, the tap of the aspirator is allowed to run slowly and the vessel refilled as required. By testing the leaves as in the previous experiments, it will be found that no starch has been formed. The plant, then, obtains the carbon for starch formation from the carbon dioxide of the air.

Oxygen is given off in photosynthesis. This may be shown by growing some water plant submerged

in a flask of water, and collecting the gas given off. Elodea is probably the best plant for the purpose, but, if this is not available, watercress, pond-weed (potamogeton) or callitriche may be used instead. Obtain a flask with a fairly long neck, put in the weed, and then quite fill it with water. Bubble a little carbon dioxide into the water and then cork with a rubber cork through which passes a tube bent at right angles twice. The part of the tube inside the flask should reach to the bottom of the neck. Now place the open end in a vessel of water. As the gas is given off from the weed it will rise to the top of the neck and force the water out through the tube (Fig. 86). Under favourable circumstances, as for instance on a warm, sunny day, the neck may become full of gas in a few hours. Now remove the cork and plunge in a glowing splinter. This does not usually burst into flame as is the case in pure oxygen, but glows more brightly, merely showing that the gas collected contains an excess of oxygen. In photosynthesis, then, a considerable amount of oxygen is evolved.

Respiration.

Respiration is not peculiar to the leaf: indeed, it is in connection with the leaf that it is most difficult to discover. But the subject is introduced here for convenience of comparison with photosynthesis, and because certain apparatus may be used for the investigation of both processes. Respiration is a process common to plants and animals.

As already indicated, green plants are the only collectors of energy. In photosynthesis, the carbon is separated from the oxygen, and by this very separation energy is stored. The carbon combines with other substances to form organic compounds, and it is the oxidation of these compounds that sets energy free to do work. Animals derive all their energy from

that accumulated in this way by plants, and it is this stored energy, too, that even the plants themselves use for most of their work. Thus we see that the whole of the carbon compounds built up by photosynthesis do not go to provide for growth. A very considerable portion of these is oxidised by the plant itself to supply energy that cannot be derived from the sunlight direct. This respiration, or the oxidising of carbon compounds to liberate energy, is going on in all parts of the plant at all times, and consequently every part of the plant is setting carbon dioxide free.

Germinating seeds, as we have already seen, respire strongly. In the rapid development and opening of a flower much energy is also employed, and hence we should expect vigorous respiration at that time. By placing opening rose buds in a bottle with their stems dipping into a shallow layer of water and tightly corking the bottle, this may be shown to be the case. The gas evolved turns limewater milky, thus showing itself to be carbon dioxide. **Opening flowers** respire vigorously.

The root has been shown to respire by growing bean seedlings with their roots dipping into limewater. The limewater, by becoming milky, shows that the root respires and gives off carbon dioxide.

From these experiments it might be thought that respiration takes place only in those parts of plants that are not green, or, in other words, are without chlorophyll. To prove that this is not the case, place a plant in an atmosphere devoid of carbon dioxide as directed in a previous experiment. Take away the aspirator and block the tube leading to it. Now place the plant in a dark cupboard, so that there shall be no photosynthesis, and after a few hours fix a U tube of baryta water, which is more sensitive than limewater, to the end that led to the aspirator, and then attach the aspirator. When the air is drawn from

the bell jar, the baryta water through which it must pass becomes milky, showing that carbon dioxide has been evolved. We thus see that even the **green aërial** parts of plants respire.

There yet remains another possible fallacy to be removed. One might suppose that these green parts respire only during darkness, relying, during the hours of light, entirely on the energy of the sunlight. It is beyond the limits of this treatise to prove that such is not the case, but it may be mentioned that careful experiment has shown that respiration goes on at all times in all parts, in the light as well as in the dark. In the sunlight the respiration of green parts is masked by the reverse process of photosynthesis, by which the carbon dioxide formed is again broken up into carbon and oxygen, so that the oxygen taken from the air is finally given back to it. But respiration nevertheless goes on.

Comparison of Respiration and Photosynthesis.

Photosynthesis is a building up process by which new substance is gained by the plant. Respiration is a breaking-down process by which substance is lost by the plant. The former is carried on only by green parts, the latter by all parts. Photosynthesis requires light. Respiration takes place in the dark as well as in the light. In the former carbon dioxide is taken in and oxygen given off, while in the latter oxygen is taken in and carbon dioxide given off.

Transpiration.

We now come to another great function of the leaf, the excretion of surplus water. Though some of the water brought from the soil is used to form carbon compounds, the bulk of it, having served its purpose of transporting dissolved minerals, passes out through the stomata into the air in the form of vapour. It has

been estimated that roughly about four hundred pounds of water is transpired, or given out by the plant, for every pound of carbohydrate formed. The **transpiration** current, as we have seen by standing plants with their roots in eosin solution, carries the water containing dissolved minerals from the root hairs through the cortex to the vessels of the wood. The course then follows these vessels through the root and stem, finally reaching the leaves, where the branching of the vascular bundles into a close network allows the solution to supply every part of the blade. We are concerned now with the means by which the surplus water is got rid of.

The **leaves** form the chief organ of transpiration. Fill two long-necked flasks with water. In one stand a leafy shoot: the geranium or nasturtium admirably serves the purpose. In the other, place a similar shoot from which all leaves have been removed. Now, to prevent evaporation, cover the surface of the water with a thin layer of olive oil (Fig. 87). Be sure to put the shoots into the water first. Otherwise the cut end will become clogged with oil. It will be found that under favourable weather conditions the water in the flask bearing the leafy shoot soon falls, while, even after several hours, the water in the other flask will remain at practically the same level. This goes to show that the leaf is the chief avenue of transpiration. The weight of water transpired by the leafy shoot may be calculated by measuring in centimetres the amount of the fall and the bore of the neck of the flask, and reckoning a cubic centimetre to the gram. By measuring the total area of the leaves the transpiration per sq. centimetre may be found. By thus using a leafy shoot under different conditions the following facts will be discovered. Transpiration is more vigorous on a **dry** day than when the air is charged with moisture. When the **wind** is blowing and the

TRANSPIRATION

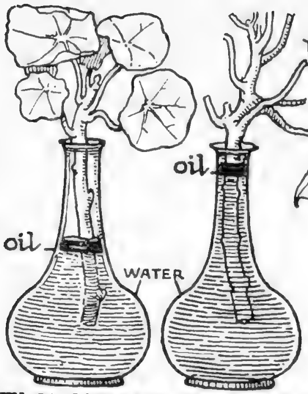


FIG.87 LEAFY·AND·LEAFLESS SHOOT·TRANSPIRING

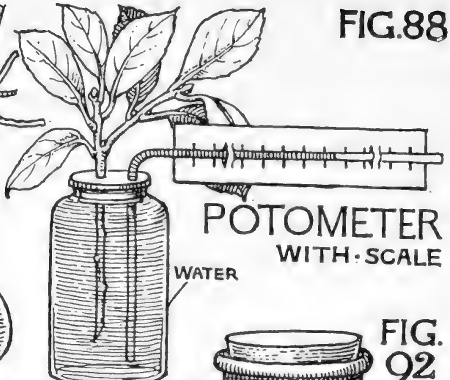
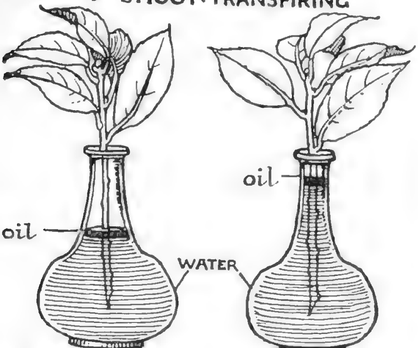


FIG.88 POTOMETER WITH·SCALE



NO·VASELINE VASELINE

FIG.89 CAMELLIA·SHOOTS

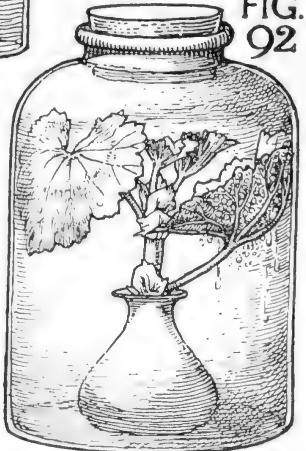


FIG. 92 BELL·JAR·CONTAINING·GERANIUM·SHOOT

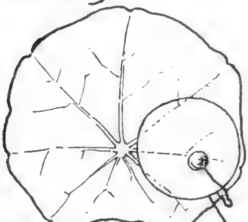


FIG.90 WATCH·GLASS·HELD IN·PLACE·BY·CLIP

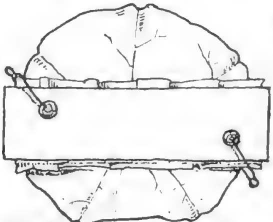


FIG.91 COBALT·PAPER·FIXED· WITH·GLASS·AND·CLIPS

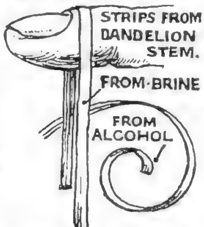


FIG.93

vapour is therefore carried away as soon as it passes out of the leaf, transpiration is again more vigorous. In a **bright light**, too, more water is given out from the leaf, because light promotes the general activities of the plant. On a **warm** day there is more transpiration, chiefly because the root is then more active.

The **potometer** (Gk. *potes* a drink, and *metron* a measure) is an apparatus (Fig. 88) for measuring accurately the loss of water by transpiration. A leafy shoot is cut from a plant, and, to prevent air from getting into the vessels of the wood, its cut end is immediately placed under water. Working under water the operator now passes the cut end through a hole in a large rubber cork, through which also passes a glass tube bent at right angles. The cork is then quickly inserted in a suitable jar full of water. The pressing in of the cork drives some of the liquid of the jar into the bent tube, which in this way is filled with water. As the shoot transpires, the water is withdrawn from the horizontal arm of the tube, so that, by measuring the area of the leaves and the bore of the tube, and finding the length emptied in a certain time, the rate of transpiration per square centimetre may be found. Here again the effect of different atmospheric conditions and the rates of transpiration in different plants may be tested. The flasks are, of course, simpler to use, but do not permit of accurate measurement of small differences.

The rate of transpiration may also be measured by actual weighing. Obtain a plant growing in a pot. Water it well, and, when it has stopped dripping cover the surface of the soil with a piece of cardboard suitably cut to encircle the stem. Weigh the whole apparatus, and, after the pot has stood for a few hours, weigh it again. The loss in weight will roughly indicate the amount of water transpired. There would, of course, be some addition to weight by photosynthesis

and a certain loss by respiration, but, for the short period involved, these will be so small that they may be neglected.

The **Stomata** provide the outlet for the water of transpiration. Place a geranium shoot in a flask of water under a bell jar, in such a way that in some cases the under and in others the upper surfaces of the leaves are in contact with the glass. If this jar be placed in a good light and the atmospheric conditions are favourable, it will be found that where the under sides of the leaves touch the glass great beads of moisture appear, while the glass in contact with the upper sides receives only a thin film (Fig. 92). It has already been noted that most of the stomata are on the under side of the leaf, and hence it would appear that the water passes from the leaf through these openings. This view is further supported by the result of the following experiment.

Using oil as before to cover the surface of the water, in separate flasks stand two shoots of some plant in which the stomata are practically all on the underside of the leaves, as is the case with the camellia, laurel, and karaka. In one shoot, block up the stomata by smearing the lower sides of the leaves with vaseline (Fig. 89). It will be found that the water falls much more rapidly in the flask bearing the shoot in which the leaves are not so smeared, again indicating that the stomata form the chief avenue of transpiration. In this experiment, a good result will not generally be obtained till after the shoots have been left standing for a few days, since all the plants mentioned are more or less drought forms, in which the thickened epidermis is specially adapted to check transpiration.

Perhaps the most satisfactory way of showing that the water is given off chiefly from the under sides of the leaves is to apply to either surface of a growing leaf a piece of filter paper soaked in a solution of

cobalt chloride and dried in an oven till the red colour changes to blue. The papers should be held in place by sheets of glass clamped together one above and one below (Fig. 91). The red colour showing that moisture is being absorbed will appear first in the paper applied to the lower surface of the leaf.

Another simple experiment may be made by fastening two watch glasses by means of a clip opposite each other on either side of a growing leaf (Fig. 90), and sealing with vaseline the edge of the glasses where they meet the leaf surface. Drops of moisture soon form on the inside of the glass in contact with the lower surface of the leaf, while the glass on the upper side will be hardly dimmed. The position of the stomata on the under side is a great advantage, for it diminishes the chance of their being blocked by water or dust.

The **Control** of transpiration is, in all plants where leaves are present, carried out by the adjustment of the stomata effected by the guard cells. When water is passing freely from the root, the guard cells become full of liquid and are said to be turgid. This has the effect of making them curve outwards and thus enlarge the stoma or opening through which the vapour passes. This curving is well seen in the filling of sausage skins, which, as they are filled assume a more or less crescent shape. When water is not being freely received by the leaf the guard cells become flaccid and assume a linear form so that, at the stoma, they come almost into contact in such a way as practically to close the opening.

Split the flowering stem of a dandelion or cat's-ear longitudinally into long strips. Place these in alcohol and they will curve much in the same way as the turgid guard cells do. By osmosis, the alcohol passes through into the cells more quickly than the denser water passes out. As, moreover, the walls of the cells

on the inside of the stem are thinner than the walls of those on the outside the diffusion is more rapid there. The greater swelling of the internal cells thus produced causes the strip to bend with these inner cells on the outside. If the piece of stem be left long enough in the alcohol it will form a coil. Now place the same strip in strong brine. The alcohol and water will by osmosis pass out of the cells more rapidly than the brine passes in. The cells will, therefore, lose much of their liquid contents, and the strips become so limp that, when suspended over the finger, they hang vertically much as is the case with the flaccid guard cells (Fig. 93).

All ordinary plants check undue transpiration by closing their stomata, but there are many plants, which, growing in situations where moisture is scanty and its conservation important, have special peculiarities of structure that adapt them to their surroundings by guarding against loss of water. Such plants are called drought-forms or **xerophytes** (Gk. *xeros* dry and *phyton* a plant). The great number of drought forms found in New Zealand indicates that the climate of this country was once much drier than it now is. The most obvious way of checking transpiration is to **reduce** the number of stomata; and this is one of the means employed in the karaka, laurel, and camellia, in which the stomata are practically all on the lower surface.

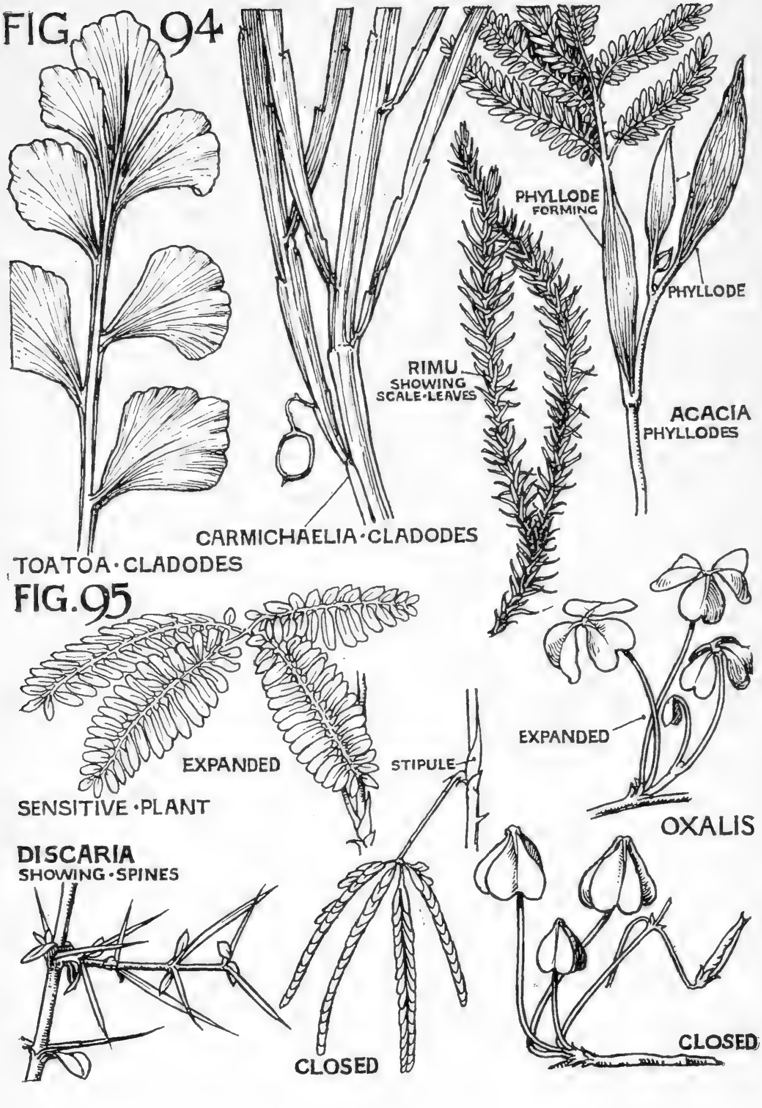
A **thickened epidermis**, which assists some plants to conserve water, is also seen in the leaves of the kauri and totara.

Leaf reduction (Fig. 94) is perhaps the commonest means of adaptation to dry conditions. In the rimu or red pine the leaves are reduced to mere scales running in rows along the pendent branches, while in the celery-leaved pines, the toa-toa and tanekaha, as well as in the New Zealand broom or carmichaelia, the

leaves have entirely disappeared, and the work of photosynthesis is carried on by flattened twigs called **cladodes** (Gk. *klados* a branch). In some plants, such as the acacia, the leaf blade ultimately disappears and the petiole and midrib flatten out to form a **phyllode** (Gk. *phyllon* a leaf). This, like the cladode, is able to carry on carbon assimilation without transpiring so rapidly as an ordinary leaf. Seedling acacias have normal compound leaves, and the transition from these to phyllodes is strikingly shown.

In the gorse and hawthorn, branches are modified to form **spines** by which means the leaf surface is reduced and transpiration diminished. In gorse, moreover, the leaves themselves form spines, and thus the transpiring surface is further reduced, a matter of importance on the dry hill sides and open heaths. In the barberry, only some of the leaves form spines. In the cactus the leaves are again reduced to spines. Not only is transpiration thereby checked, but the spines at the same time protect against animals the **fleshy stems** which have accumulated reserves of food and water to tide the plant over the long periods of drought that prevail in its desert home. The ice plant produces fleshy leaves in which also water is stored. The Wild Irishman (*Discaria*) (Fig. 95) adapts itself to the seasons. In spring, the leaves are fairly abundant, but, as the season advances, they become gradually reduced in number, till, by the autumn, they have entirely disappeared, the work of photosynthesis being carried on by large green spines. This places on transpiration the check that is so needed on the sand dunes that form the habitat of *Discaria*. Dr. Cockayne's historic experiment with this plant has earned world-wide fame. Grown by him from the leafy seedling form in a warm moist atmosphere it was found that the leaves were retained and spines were not developed. This indicates that the Wild Irishman

ADAPTATIONS



once had small thin leaves suited to a warm moist habitat, and became modified to its present form in response to changes of climate resulting in drier conditions; for a plant, in its individual development, sums up the history of the development of the type to which it belongs.

The dense felt of slender **woolly hairs** that covers the exposed parts of the vegetable sheep (*Raoulia*) not only reduces the loss of moisture by impeding the escape of the transpired water, but, by forming a non-conducting layer, protects the plant, as by a blanket, against excessive heat and cold.

In the tauhinu, a small shrub common all over the gum lands, the leaves are rolled back to form a **wind-still tube** from which the transpired water does not readily escape. In a similar way, to prevent wilting, grass leaves in the young stage are folded to enclose the stomata; but, as the epidermis thickens, they unfold and assume a more horizontal position to receive the rays of light.

Soil water is conserved by **creeping** and **rosette plants**, which, by their shade, prevent evaporation from the surface. The spinifex and calystegia of the sand dunes are good examples of the former, whereas the plantain, dandelion, and cat's-ear illustrate the latter.

Cushion plants, too, like the vegetable sheep just mentioned, also shade the soil.

Protection of Leaves.—Already we have seen how bud scales and exudations of gum prevent the tender leaves from drying out, and how, in the vegetable sheep and many other alpine plants, a hairy surface serves as a protection against **heat** and **cold**. In the brier and Scotch thistle, again, the spiny leaves act as a safeguard against grazing animals, while doubtless the unpleasant taste of the poppy and poisonous nature of the ragwort serve the same purpose. The leaves of

the oxalis (Fig. 95) are, during the day, spread out to the sun, but at night they assume a vertical position. By reduction of the exposed surface, loss of heat by radiation is diminished, so that this is probably a protection against cold. In the sensitive plant (Fig. 95), a small shrub of the mimosa family, the leaflets fold together, and the whole leaf bends down as on a hinge in response to any sudden shock. This may easily be a protection against gusts of **wind**. Leaves must be protected against the adhering of **water** to their surfaces, for water would block the stomata. This may be prevented by a smooth surface, as in the laurel and karaka, or by a felty covering as in the mullein and many of the native celmisias. In some tropical plants the whole leaf surface resembles a drainage system, the blade being channeled and the tip prolonged into a kind of gutter, which rapidly conducts away the rain.

Leaf Forms.

The shapes of leaves are as a rule decided by three factors. To promote photosynthesis and transpiration the blades tend to become as large as possible: on the other hand, where environment renders it necessary to check transpiration, the tendency is to reduce the leaf surface; while, to guard against injury by winds or running water, leaves may be narrowed or divided.

The commonest form of leaf blade is more or less egg-shaped as may be seen in the lilac and *Coprosma robusta* (Fig. 96). Such a leaf is said to be **ovate** (L. *ovum* an egg). Many modifications of this leaf occur to suit different conditions and surroundings. Where the blunt end is turned outwards as in the karaka the leaf is **obovate** (Fig. 96). When the blade is rather heart, than egg-shaped, as in the kawakawa or New Zealand pepper (Fig. 96), it is **cordate** (L. *cor* the heart), and where the heart is reversed, as in the obcordate myrtle (Fig. 96) and the leaflets of the

oxalis, it is **obcordate.** A kidney-shaped leaf, as in the kidney fern (Fig. 97), is termed **reniform** (L. *renes* the kidneys). When the broad base of the leaf has pointed lobes extending like a spear horizontally, as in the case of the arum (Fig. 97), it is **hastate** (L. *hasta* a spear), but where the lobes extend downwards, as in the convolvulus (Fig. 97), the leaf is **sagittate** (L. *sagitta* an arrow). The **spatulate** or spoon-shaped form is seen in the daisy (Fig. 97) and in *Coprosma spatulata.*

Where the petiole comes off, not from the edge but from the middle of the blade, as in the nasturtium (Fig. 97) and Mount Cook lily (*Ranunculus lyalli*) the leaf is **peltate.** If the leaf is considerably narrowed but still tapers towards the tip, as in the willow, peach, and tawa (Fig. 98) it is **lanceolate,** and where the blunt end is turned outwards, as in the hinau (Fig. 98) and akeake, it is **oblanceolate.** The native flax (Phormium) has a sword-shaped or **ensiform** (L. *ensis* a sword) leaf (Fig. 98). If the narrowing is further continued, the leaf becomes **linear** as is the case in the mingimingi (*Cyathodes*) and most grasses (Fig. 98). The strap-like form assumed by many sea weeds, and by the leaves of vallisneria is doubtless to prevent injury by moving water. Further reduction of the blade results in a needle-like leaf termed **acicular** (L. *acus*, a needle). This is well seen in pinus insignis (Fig. 98).

This progressive reduction of the leaf blade is in almost all cases to adapt the plant to dry conditions by guarding against excessive loss of water by transpiration; though, in some instances, it guards against the effect of wind as well.

The **veining** of leaves is of two main types, **reticulate** (L. *rete* a net) or net veined, and **parallel** veined. Most dicotyledons, as the dandelion, apple, mahoe and coprosma (Fig. 99) are net veined, while most monocotyledons, like the lily, grass, cabbage tree

LEAF FORMS

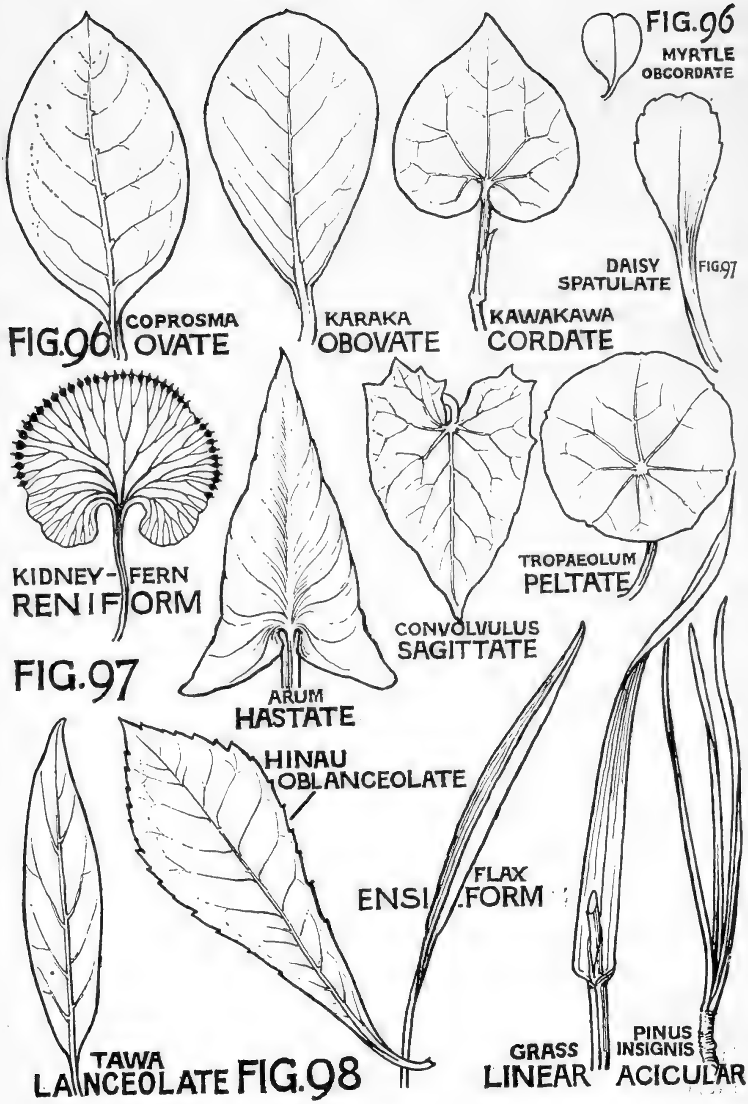


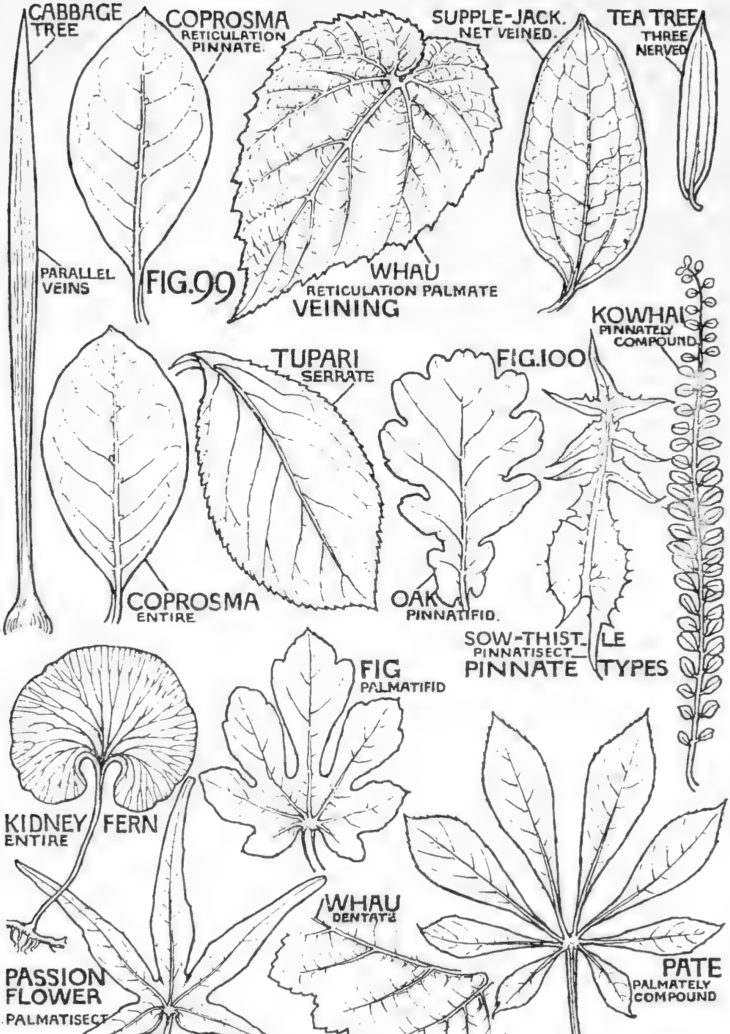
FIG. 96
MYRTLE
OBCORDATE
COPROSMA
OVATE
KARAKA
OBOVATE
KAWAKAWA
CORDATE
DAISY
SPATULATE
FIG. 97
KIDNEY-FERN
RENIFORM
FIG. 97
ARUM
HASTATE
CONVOLVULUS
SAGITTATE
TROPAEOLUM
PELTATE
HINAU
OBLANCEOLATE
FLAX
ENSIFORM
TAWA
LANCEOLATE
FIG. 98
GRASS
LINEAR
PINUS
INSIGNIS
ACICULAR

(Fig. 99) and New Zealand flax are parallel veined. The supple-jack (Fig. 99) is exceptional, for, though a monocotyledon, it has net-veined leaves. In net-veined leaves the branching may be **palmate** as the fingers branch from the palm of the hand, or **pinnate**, as the branches come off a feather (L. *pinna* a feather). The pinnate arrangement is the commoner, and is well seen in the peach, cherry, and coprosma (Fig. 99), while the palmate type is shown in the whau (Fig. 99), violet, geranium, ivy and buttercup. The tea-tree leaf has, in addition to its midrib, a strong vein or nerve extending from the base along either edge almost to the tip. (Fig. 99).

The **margins** of leaves may in some cases, as in the privet, tea-tree, kauri, and coprosma (Fig. 100) be **entire**, *i.e.*, unnotched. The notching of the leaves that occurs in so many plants, seems, to a considerable extent, to be dependent on the arrangement of the veins. Where the veining is **pinnate** the notching is **serrate** (L. *serra* a saw), the teeth being all inclined upwards from the base towards the apex, as is the case also with the veins. Such is the case in the plum and tupari (*Olearia colensoi*) (Fig. 100). Where the margin is waved instead of notched, as is the case with the kohuhu (*Pittosporum tenuifolium*), a common hedge plant, it is said to be **sinuate** (L. *sinus* a fold). In many palmately veined leaves the notching is **dentate** (L. *dens* a tooth), the teeth pointing outwards in the direction taken by the veins. Such is the case with the whau (Fig. 99) and the lobes of the buttercup leaves. Where the teeth are rounded, as in the violet and Mount Cook lily, the margin is **crenate**.

Let us now follow the pinnate type from the entire form through various stages of notching, till finally the blade is divided into distinct segments and we have a pinnately compound leaf (Fig. 100).

VEINING AND MARGINS



In the coprosma the margin is entire and in the tupari it is serrate. In the oak the indentations are much deeper and the leaf is **pinnatifid** (L. *findo fidi*, I cut), while in the poppy and sow-thistle, being deeper still, they produce a **pinnatisect** (L. *sectus*, cut) blade. The last step is seen in the leaves of the bean, wistaria, kowhai and clianthus, where the indentations reach the midrib, and the leaf is **pinnately compound.**

In following the palmate type (Fig. 101), we have the margin entire in the kidney fern and kawakawa, and dentate in the whau. In the fig, the deeper indentations give a **palmatifid** leaf, while in the passion flower, being deeper still, they produce the type termed **palmatisect.** Finally, in the horse-chestnut, panax and pate (*Schefflera digitata*) the divisions meet at the base of the midrib and the leaves become **palmately compound.**

It has been noted that, as a rule, leaves which, like the tobacco, sunflower and rangiora can raise themselves freely to the sun and air, are broad, flat and horizontal; but, in crowded situations, as a hedge or grassy meadow, where leaves are competing with one another for the sunlight, special forms have been developed suited to the particular environment. In the struggle for existence, the fittest have survived and the less fit have gone to the wall. In meadows, where the grasses are densely crowded, the leaves are narrow and grow upwards to the light without the delay that would arise from the production of a broad blade, for the development of which there would be insufficient room. In hedges, and in the shade of the forest, the leaves are generally much divided, as we see in vetches and cleavers and the great variety of ferns that clothe the forest floor. The leaflets of their compound blades wave freely in the air, forming a kind of network to arrest such carbon dioxide as may be present in the

air, and intercept such rays of broken sunlight as have filtered down through the taller plants above.

Variety of leaf form is a striking characteristic of water plants. In the leaf of the water-lily, for instance, which spreads itself on the surface of the water where there is not likely to be interference by other plants, the blade is broad and expanded, indeed almost round in form. Where, on the other hand, the leaves of a water plant are submerged, they are divided into many segments, that they may wave to and fro and secure what little carbon dioxide there is dissolved in the liquid around them. This point is well illustrated by comparison of the aërial and submerged leaves of the watercress. The former are but little divided, whereas the latter are cut up into numerous segments.

Division of the leaf blade often serves other purposes. A leaf divided into small segments is not so likely to be torn by wind or water as one in which the blade is broad and presents a large and unyielding surface. This, in part, accounts for the division of the submerged leaves of the watercress.

The advantage of a divided blade is further strikingly illustrated by a comparison of the effect of wind in the huge undivided leaves of the banana tree and on the leaf of the kowhai with its many small leaflets. In the Albert Park at Auckland the two plants are growing in close proximity, and, while the former is ripped and torn, the latter remains practically unharmed.

The **apex** of a leaf may be **acute**, as in the willow and tawa, **obtuse** as in the rewarewa (*Knightia*) and **pungent**, as in the totara and tea-tree, where it has a hard, sharp tip. Leaves which, like those of the wall-flower, the tea-tree and miro, have no petiole, are **sessile**, while all others are **petiolate**.

Grass leaves, it will be noted have long sheathing bases, and just where the sheath begins to clasp the stem is a membranous scale called a **ligule**.

Stipules are outgrowths from the leaf base or sheath, well seen in the bean, rose, and kawakawa.

Modifications of leaves to suit special conditions have already received attention. Leaves are modified for **climbing** in the clematis and the pea, to form **spines** in the barberry, and to form **traps** for insects in the pitcher plant and sundew. The more important modifications to form bracts, spathes and floral leaves of different kinds will be dealt with in connection with the flower and inflorescence.

Plants that are completely parasitic, like the broom-rape and dodder, have no leaves and no chlorophyll since photosynthesis is unnecessary.

Foliage Leaves and Seed Leaves.

Foliage leaves are distinctly **organs** of the plant doing work necessary to its existence; *i.e.* carrying out the process of photosynthesis and forming an avenue for the ingress and egress of gases as well as a means of exit for the water of transpiration. Seed leaves, on the other hand, are merely **storehouses** of reserve material, which will supply the young seedling with nourishment until it has obtained a root-hold and become green, and thus reached a stage at which it can fend for itself.

The **starch** stored in the foliage leaves is stored only for a short period and is for immediate use, while that accumulated in the seed leaves is stored for a long period, and is not called into requisition till the seed germinates.

The foliage leaves contain chlorophyll for carbon assimilation, while the seed-leaves, having no such function to perform, have no chlorophyll.

The cotyledons are thick and solid, while the foliage leaves are more or less thin and membranous.

In most plants the cotyledons grow smaller as the store of reserve is used up, while foliage leaves, on the other hand, grow larger. This, however, is not true of the pumpkin and several other plants, in which the seed leaves grow larger and become green.

Summary.

The leaf takes **carbon dioxide** from the air and by means of its **chlorophyll** utilizes the energy of the **sunlight** to carry out photosynthesis. The arrangement of leaves on the stem and the formation of leaf mosaics indicate the light relation.

Structure.—The **upper epidermis** is protective and has but few stomata, the lower has many stomata that provide for ingress and egress of gases and exit of water. The **mesophyll** has many air spaces and contains chlorophyll.

Photosynthesis is the process by which, in the presence of chlorophyll and sunlight, carbon dioxide is decomposed and the carbon built up with the elements of water from the soil to form organic compounds. The carbohydrate is stored temporarily in the leaf as starch. **Amides** are formed by the addition of nitrogen. The carbohydrate circulates in the plant in the form of sugar, and may form starch, inulin, or cellulose. The amides, with sulphur and phosphorus, form proteins. Not all the material formed goes to build the plant, some is oxidised to supply energy.

Without **iron** chlorophyll is not formed and without **potash** there is no photosynthesis. **Light** is proved to be necessary by covering parts of leaves, and **chlorophyll** by testing variegated leaves. The **oxygen** given off may be collected. To prove that the carbon comes from the **carbon dioxide** of the air grow a plant in an atmosphere devoid of that gas.

Respiration is the oxidation of organic compounds to supply energy. Carbon dioxide is evolved. This can be shown to be most vigorous at germination and flowering, and can be proved to take place in the green aërial parts as well as in the root. Compare with Photosynthesis.

Transpiration is the giving out of the water absorbed by the root and transmitted through the vessels of the wood to the leaves. It takes place through the stomata of the leaves. It is more vigorous in the light, in a dry atmosphere, when it is windy, and when it is warm. The **potometer** measures the rate of transpiration. The **control** of transpiration is by the opening and closing of the stomata through the varying turgidity of the **guard cells**.

Xerophytes guard against loss of water by thickened epidermis, leaf reduction, petioles forming **phyllodes** and twigs **cladodes**, and some by changing their leaves into **spines**. Fleshy stems conserve water in the plant, and creeping stems, rosette and cushion plants check evaporation from the soil.

Protection.—Scale leaves protect against drying out, hairs against heat and cold, and hair, spines, poison, and bad flavour against grazing animals. Water is prevented from adhering by glossy surfaces, hairs and gutter-like points.

Shapes.—Ovate, obovate, cordate, obcordate, reniform, peltate, hastate, sagittate, spatulate, lanceolate, oblanceolate, linear, and acicular. Reduction suits dry conditions.

Veining is reticulate (pinnate and palmate) and parallel. Margins are entire, serrate, dentate, crenate. Pinnatifid, pinnatisect and pinnately compound leaves are derived from leaves pinnately veined. Palmatifid, palmatisect and palmately compound leaves are derived from leaves palmately veined. Division of the blade helps leaves to gather carbon dioxide and obtain

sunlight, and protects against wind and running water. The **apex** may be acute, obtuse, or pungent. Leaves may be **sessile** or **petiolate**. Grasses show a **ligule.** **Stipules** are outgrowths of the petiole base. The leaves of pitcher plants and sundews **trap insects.** Complete **parasites** have no leaves. Compare foliage and seed-leaves.

QUESTIONS ON CHAPTER V.

1. What do you consider the twelve most important facts about leaves?
2. What leaves are used by man? For what purposes are they used?
3. Define the terms venation, pinnate, palmate, serrate, linear, obovate, giving examples of each.
4. What are the chief functions of leaves?
5. What is transpiration? How is it regulated? What experiments have you made relating to transpiration?
6. How can you show the course taken by the transpiration current?
7. Under what circumstances must plants check transpiration? Explain a few of the ways in which this is done.
8. What is respiration? How does it differ in plants and animals?
9. How would you show (*a*) that the green parts of a plant give off oxygen, (*b*) that carbon dioxide is given off by a plant?
10. The leaf is the factory of the plant. Explain this.
11. What is photosynthesis? How did you show that sunlight and chlorophyll are necessary to photosynthesis?
12. Describe the tissues of a leaf. State all you can find out without a microscope, and explain the function of each part.
13. Where does a plant get its carbon from?
14. How are leaves protected against cold, heat, wind, and grazing animals?
15. What circumstances determine the shapes of leaves?
16. Give a summary of the gaseous exchanges of a plant.

17. Draw roughly to scale the largest and the smallest leaf you know.
18. How could you prove that a leaf has air spaces in it and air pores leading to the surface?
19. Whence does a green plant derive the energy necessary to carry on its vital processes during periods of darkness?
20. What are the "veins" of a leaf? What are their uses? What experiment could you make in illustration?
21. Why are the inside leaves of a cabbage paler in colour than the outer ones?
22. Why do plants droop on a hot day and recover their freshness in the evening?
23. What are stipules? What purposes may they serve? Make drawings of three different leaves showing different types of stipules.
24. What is a stoma, and how does it work?
25. What advantage is gained by spraying the leaves of plants growing indoors or by a dusty road?
26. What are the essential characteristics of all foliage leaves?
27. What is chlorophyll and what purpose does it serve?
28. Why should a variegated bamboo not grow so vigorously as one which is green in all its parts?
29. What are the chief external conditions that affect the rate of transpiration?
30. How would you obtain a solution of chlorophyll?
31. What is the potometer and how is it used?
32. Explain some of the different arrangements by which plants secure the maximum illumination for their leaves? Make illustrative drawings.
33. Enumerate the series of processes by which the nitrogenous compounds of plants are built up. What elements enter into these compounds? Whence does the plant obtain each of these elements?
34. What are the conditions essential to photosynthesis?
35. Under what conditions is chlorophyll replaced by etiolin?
36. How would you prove that the different parts of a plant respire? At what periods in the life history of a plant is respiration most vigorous?
37. What are cladodes and phyllodes? Under what circumstances are they formed, and what advantage does the plant derive therefrom?

Chapter VI.

FLOWER AND FRUIT.

The flower is the **reproductive** organ of the plant. We have already considered vegetative reproduction whereby a portion is severed from the plant body and established as a new individual. In such cases the offspring may be regarded as merely a part of the parent growing independently in a different place. There has been no break in the continuity of the life processes. There has been nothing but ordinary growing or multiplication of cells to produce new stem, root, and leaves. True sexual reproduction in which the flower is concerned is an entirely different thing. Each time there is reproduction through the flower an absolutely new start is made from a single cell, and the seed which is the finished product is really a young plant of a new generation. It is the **flower** then that forms the connecting link between one generation and another. Within it and forming part of it are the structures which produce and protect the seed.

Already we have seen that most ordinary flowers have sepals for protection, petals for the attraction of insects, stamens for the production of pollen, and carpels to protect the ovules which develop into seeds. The surprising thing is that all these members of the flower do not differ in origin from ordinary foliage leaves. It would not be right to affirm that they are modified foliage leaves. It is nearer the truth to say that among the earliest plants there was no distinction between foliage and floral leaves, but that, as time went on and a variety of plants arose, there were some in which certain leaves restricted themselves to the work of photosynthesis and transpiration, while others devoted themselves entirely to the work of

reproduction. The former became the foliage, the latter the floral leaves. If we examine the leaves of an ordinary fern we shall find that practically all of them are both assimilatory and reproductive. They contain chlorophyll for photosynthesis, and have, along their margins, spores for reproduction. In the lomarias (Fig. 102), and some other forms, however, there are special leaves which alone bear the spores; and in these the green blade is much reduced. These leaves have been specialised for reproduction. The floral leaves of a flowering plant have of course become much more highly specialised than the reproductive leaves of the lomarias, but, nevertheless, one helps us to understand the other. Again, though in most flowers the distinction of the parts is clearly marked, there are others, like the water-lily, cactus, and anemone in which there may be a gradual transition from one kind of member to another, so that it is impossible to say where the sepals end and the petals begin, or, indeed, to make a sharp line of distinction between any two groups of members. This would indicate that the members of the different whorls or rings forming the flower have had the same origin. The primrose flower will often carry us a step further. In this flower, especially in certain varieties, the sepals occasionally have the form of foliage leaves. The structure, veining, and texture exactly correspond. This connects the foliage leaves with the sepals, and, through them, with petals, stamens, and carpels. A flower, then, is a shoot in which the leaves are specialised for reproductive purposes and have been crowded together, generally in rings or whorls, on the much-shortened branch which forms the stalk, and is continued as the **receptacle** of the flower. The receptacle is that part of the shortened branch to which the various whorls of the flower are attached. It is generally soft and fleshy and, as a rule, somewhat

swollen. In some cases, as in the strawberry, blackberry, and apple, it eventually forms an important part of the fruit.

The **Sepals,** which form the lowest whorl of the flower, and vary in number according to its kind, are collectively known as the **calyx**. They are the most like foliage leaves, for they are generally green, and are thus fitted to help in the work of photosynthesis. The sepals may be quite distinct from one another, as in the buttercup, in which case the calyx is termed **aposepalous** (Gk. *apo.* away) or they may be united to form a tube, as in the bean and apple, when the calyx is said to be **synsepalous** (Gk. *syn* together).

At this stage a word or two on **evolution** will not be out of place. It is reasonably certain that the plants that exist on the earth to-day have had common ancestors. Slight variations, arising from time to time in individual descendants, have, in the course of ages, resulted in the vast variety of species that at present covers the earth. Careful investigation leads to the conclusion that certain types of plants and certain forms and arrangements of parts are more primitive than others. We shall find that there are plants which deviate widely from the most primitive type in all respects. In these, there has been progressive development or evolution in all directions. In others again the development has been only partial and fragmentary. Certain organs may have become highly differentiated, while others have retained their primitive form and arrangement. Here evolution has been restricted to certain lines. As an example of progressive development may be mentioned the union of the sepals to form a tube, as seen in the bean. This may be contrasted with the more primitive free condition of the members forming the calyx of the buttercup or pansy. Other cases will be dealt with as they arise.

The great function of the sepals is to **protect,** especially while in the bud, the interior parts of the flower, not only from the attacks of insects but from excessive evaporation, as well as cold and rain. The importance of the calyx, as a protection against extreme cold, is often well seen in the spring. If, after some of the flower buds have opened on the fruit trees, there comes a cold snap, it will be found that the flowers in which the calyx has expanded, will, in most cases, drop off the trees; while those that were still protected by the sepals remain unharmed and form fruit in the ordinary way. If there appears to be danger of a late frost, fruit growers will often build smoky fires in their orchards to check radiation of heat, and thus save the opening buds. During the winter of 1910 the author was investigating certain peculiarities of the flower buds of the ixerba (*tawari*), a beautiful tree found in the northern parts of New Zealand, and especially plentiful on Te Aroha mountain. In the course of the investigation, it was necessary, about mid-winter, to remove the sepals from a number of these buds, which, though they are well formed by the end of May, do not usually expand till November. For three weeks after this mutilation the weather was mild and fine, and the petals began to show signs of unfolding. At this stage, however, there was a whole week of rain, at the end of which it was found that the petals were beginning to decompose. The decomposition was soon communicated to the stamens and pistil, and, as a result, the whole flower was rendered useless. In some cases, especially where petals are absent, as in the clematis and anemone, the calyx becomes petaloid or petal-like, and, by attracting insects, does the work of petals.

The **petals** and sepals together form the **perianth** while the petals alone constitute the **corolla**. While in a measure protective, the petals are concerned mainly

with the attracting of insects, without which many flowers are unable to produce fruit and seeds.

The members of the corolla, which vary in number according to the flower, may be free or united. In the one case they are **apopetalous** and in the other **synpetalous,** the former, well seen in the buttercup, being a more primitive condition than the latter, which is strikingly exhibited in the foxglove. It is from the corolla, as a rule, that the flower takes its characteristic form, and from it usually arises its perfume. Where the petals are symmetrical, both as to size and arrangement, as in the buttercup and apple, the flower is said to be **actinomorphic** (Gk. *aktinos* a ray and *morphe* form), and where this is not the case, as in the pea and snapdragon, it is **zygomorphic** (Gk. *zygon* a yoke). The zygomorphic form is less primitive than the actinomorphic, and is obviously more adapted to arrest the attention of insects.

Attraction.—Insects visit flowers for their food—either nectar alone, as in the case of moths and butterflies, or nectar and pollen, as is the case with bees; but, in every instance, it is the size, shape, colour, or perfume of the flower that indicates where the food is to be found. To show the part played by the petals, remove the corollas from some of the flowers on a plant commonly visited by insects. The flowers so mutilated will be passed over, though their near neighbours may be visited repeatedly. The experiment is not so conclusive as it appears, for, by removal of the petals, there is generally taken away the support on which the insect stands while gathering its food. Different insects show a partiality for different colours, and one has only to watch a mixed flower border for an hour or so to see that the bees prefer blue and violet, are indifferent to yellow, and seem to avoid scarlet. Scarlet sweet peas intermingled with blue are left unvisited, while the latter swarm with bees.

Flies, on the other hand, appear to be specially attracted by yellow. Sunflowers will seldom be without one or more of these insects. Flowers that depend on the visits of night-flying insects are generally white, as is the case with the clematis and many other New Zealand flowers. Their perfume, which arises only after sundown, is the means of attraction in the evening primrose and night-scented stock. At night, too, the kohuhu (*Pittosporum tenuifolium*), a common native shrub much used for hedges, diffuses a delicious perfume, doubtless for the same purpose, though the dark colour of its flowers affords no assistance to night-flying insects.

Protection.—The petals, as well as the sepals, may serve to protect the essential inner parts of the flower, especially the pollen, after it has been shed from the anther. This protection may be permanent or temporary, in the latter case arising merely as occasion requires. In the bean, the folded keel protects the pollen, in self-heal the arched roof, and in the polyanthus the constricted tube of the corolla serve the same purpose. In the potato, temporary protection is afforded by the drooping of the flower when rain is threatening, while in the water lily the pollen is shielded from the dew by the nightly closing of the petals. **Temperature** plays an important part in the opening and closing of many flowers. On a cold frosty morning interesting experiments may be made with a crocus flowering in a pot. Left exposed to a temperature not exceeding 15° C., it remains unopened, but, if taken into a room heated to between 20° and 25° C., it will at once begin to unfold. The advantage of the protection thus afforded to the pollen against frost and snow is essential to a flower that matures so early in the spring.

Light, too, exerts an important influence in connection with the opening and closing of flowers.

Dandelion and oxalis flowers, for instance, close when removed to a dark place, no matter what may be the temperature or what the time of day. This affords the pollen protection from the dews and frosts. The opening of a flower bud is due to more rapid growth on the inside than on the outside of the petal base. Temporary opening and closing are produced by greater turgidity of the cells on the inner and outer sides respectively.

Essential Parts. We now come to the essential parts of the flower to which all others are subsidiary Even the vegetative organs of the plant—root, leaves, and stem—may be regarded as merely providing a means of producing and supporting these. The stamens and carpels alone are directly concerned in the actual work of reproduction, and it is to secure the proper functioning of these that the whole effort of the plant is concentrated. It is these that the sepals protect, it is to these that the petals attract.

The **Stamens** collectively form the **andrœcium** (Gk. *andros* a man and *oikos* a house). They vary in number far more than the members of the first two whorls. They are usually **free**, as in the buttercup and rose, though in a few flowers, such as those of the bean and gorse, some or all of them are united. The free condition is the more primitive. Each stamen, as a rule, consists of two parts, the **filament** or stalk and the little knob or **anther** at the tip. The anther generally has two lobes separated by a vertical depression. Each of these lobes is a **pollen sac** which eventually opens or **dehisces** to set free the little grains of pollen that are essential to the development of fruit and seed. Where the anther opens towards the interior of the flower, as in the case of the buttercup, the dehiscence is said to be **introrse**, and where it opens towards the outside, as in the iris, it is termed **extrorse**.

The part of the anther uniting the lobes is called the **connective.** In the violet this is in each stamen produced into a little hood, while in two it is prolonged backwards into a spur: in the salvia it is enormously enlarged. In the violet and some other flowers, the filament has almost disappeared and the anthers may be regarded as **sessile.** To show the importance of pollen, take away the stamens from a number of flowers while still in bud. Cover these with paper bags tied tightly round the stalk so that no pollen may reach them from outside. It will be found that the flowers so treated will not set fruit, though normal flowers on the same branch do so in the ordinary way.

Carpels. Whereas the stamens constitute the male, the carpels form the female reproductive organ of the flower. These develop into the fruit and contain the ovules that eventually become the seeds. The carpels of any one flower are collectively known as the **gynœcium** (Gk. *gyne* a woman and *oikos* a house). The gynœcium may consist of a single carpel, as in the bean, of a number of separate carpels, as in the buttercup, or a number of united carpels, as in the lily. The term **pistil** requires careful consideration. Where the gynœcium consists of only one carpel or a number of united carpels, the term pistil and gynœcium signify the same thing, *i.e.*, the whole female organ of the flower. When, however, the gynœcium consists of a number of separate carpels, each carpel is a pistil, so that, while the pea and lily have only one, the buttercup has many pistils. In such cases the terms carpel and pistil refer to the same thing.

As a rule, each pistil has at its base a swollen portion called the **ovary** which encloses and protects the **ovules.** Rising from this is a slender lengthened portion called the **style,** and, on this, usually at the tip, is a moist sticky surface called the **stigma.**

PLACENTATION

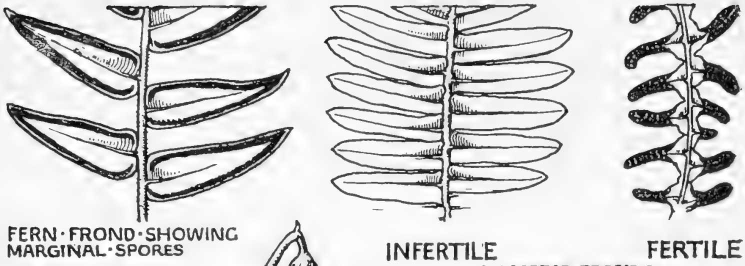


FIG. 102

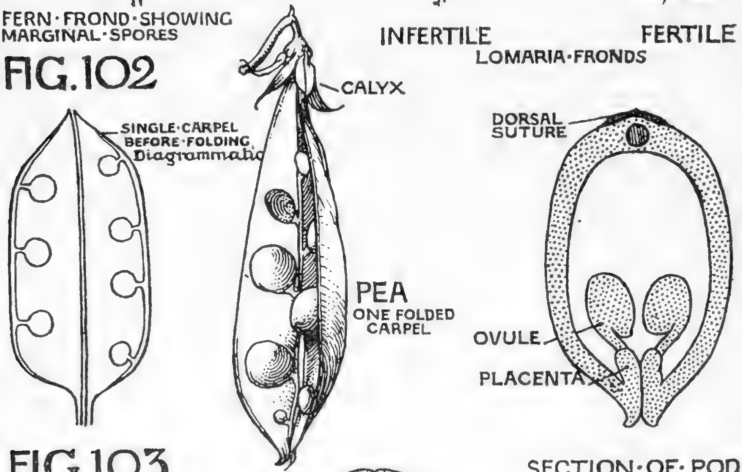


FIG. 103

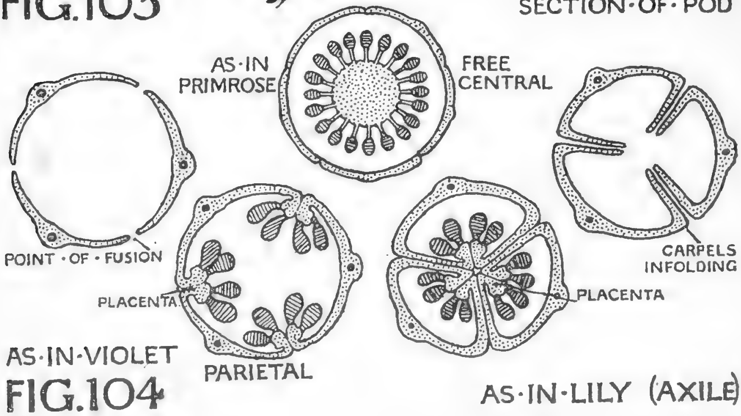


FIG. 104

To understand the structure of the ovary it will be necessary to revert once more to general principles. Already we have seen how ferns bear their reproductive organs along the edges of their leaves (Fig. 102). We may consider carpels as similar leaves which have folded in such a way as to bring their margins together and enclose the reproductive organs. In the pea, there is only one leaf, and, by cutting out an oblong piece of paper and marking the ovules along the edge, a rough model of this may be obtained. Now fold the two edges together, and we have a pod with the ovules attached along either side of the line of union. This line of union forms the **ventral suture** while the fold down the back which indicates the position of the midrib of the original leaf is called the **dorsal suture**. The pod shown in Fig. 103 is split along the dorsal suture. The **placentation** of the ovules, when thus attached to the inside of an exterior wall, is said to be **parietal** (L. *paries* a wall.) When, however, a single ovule rises from the base of the ovary, as in each carpel of the buttercup, the placentation is **basal.** Let us next consider ovaries that are formed from more than one carpel (Fig. 104). In the violet, three carpels are united by their edges to form a single chamber.

The placentæ, or parts to which the ovules are attached, are at the three junctions of the carpellary leaves. Thus there are three groups of ovules springing from the interior of the wall and the placentation is again parietal. In the lily, however, the edges of the three leaves fold right in till they meet at a point, and at the same time grow together to form a single body. In this way a round three-chambered structure is formed with the placentæ all massed together along the central axis. Each chamber or cell has at its inner corner a mass of ovules derived from the two edges of a carpellary leaf. This form of

placentation is **axile** and the ovules are, in the lily, situated on three axile placentæ. Externally, the lines of union as well as the midribs of the carpellary leaves may easily be distinguished.

Free central is a further development from axile placentation. First the leaves bend in, and, as before, mass the ovules on placentæ forming the central axis. The ovary has now as many chambers as there were carpellary leaves, each chamber being divided from the others by the wall or **septum** formed from the infolded parts of two adjacent leaves. In some flowers, as for instance the primrose, these septa disappear and the ovules are left attached to an axis which stands free in the centre: hence the term **free central**. In the carrot, parsnip, and other members of that family the ovules are **suspended,** *i.e.*, hang, one from the roof of each chamber of the ovary. Where the carpels are united, as in the lily and the primrose, the gynœcium is said to be **syncarpous**, but where they are free, as in the buttercup, it is **apocarpous.**

The **style** serves the purpose of lifting the stigma to the position most convenient for receiving pollen. It is generally straight, but in the pea and violet it is bent almost at right angles.

A **stigma,** which, owing to the absence of a style, lies immediately on top of the ovary, as is the case with the tulip, is said to be **sessile**. The stigma is the receptive part of the pistil. It receives and holds the pollen grains, and provides them with a sugary nutritive material that enables them to germinate. If the stigmas be removed from a number of flower-buds the seeds will not develop. The pollen grain germinating on a stigma sends down to the ovule a tube, which enters the micropyle and discharges a dense piece of protoplasm called a **nucleus**. This nucleus fuses with a similar but larger structure called the **egg cell,** which is situated in the ovule itself. It

is from the body formed by this fusion of the pollen nucleus with the egg cell that the embryo develops. It is necessary here to distinguish the terms **pollination** and **fertilization.** Pollination occurs when the pollen grain reaches the stigma, but fertilization does not take place till the pollen nucleus fuses with the egg cell. To investigate the latter process would need a microscope and is therefore beyond our scope. Pollination, however, is well within our range, and forms one of the most fascinating branches of the science of botany.

Nectaries.—Though insects are attracted to the flower by its size, shape, colour, and perfume, it is in the expectation of obtaining nectar that their visits are actually made. This nectar is a sweet fluid produced by nectaries, which are little swellings that may arise in almost any part of the flower. In the buttercup, for instance, the nectary is at the pointed base of the petal, while, in the wallflower, it is where the stamens spring from the receptacle. A profusion of nectar is produced by many native plants, among which may be mentioned the flax, fuchsia, rewarewa, and pohutukawa. In some flowers, such as the iris and pansy, there are markings that point out the way to the nectaries. These are the so-called honey guides. Nectaries are always so situated that when the proper insect secures the nectar they secrete, it must of necessity also accomplish or take a step towards accomplishing the work of pollination.

Adhesion and Cohesion (Fig. 105).—In some flowers, parts that must originally have been free have grown together. This has already been noted in the case of the carpels of the lily and violet, as well as in the corolla of the foxglove and calyx of the bean. Where the union is, as in the cases mentioned, between members of the same whorl, we have what is called **cohesion.** Where, however, the union is between

members of different whorls there is said to be **adhesion**. For instance, in the snapdragon and narcissus the stamens are fused with the petals and are therefore said to be **epipetalous**. In the most primitive arrangement of the flower whorls, the sepals spring from the lowest part of the receptacle, the petals are given off above them, and these are followed, in succession, by the stamens and carpels. In such cases, the calyx is said to be **inferior**, the petals and stamens **hypogynous** (*i.e.*, below the gynœcium) (Gk. *hypo* under) and the ovary superior. In some flowers, the part of the receptacle bearing the sepals, petals and stamens is lifted up to form a ring or tube round the gynœcium, but without touching it. In such cases the flower is said to be **perigynous** (Gk. *peri* round about). In all perigynous flowers there is a clear space, though sometimes very narrow, between the receptacle tube and the gynœcium. Where the receptacle carries the petals and stamens right to the top of the ovary and fuses with it we have an **epigynous** flower in which corolla and andrœcium are on top of the ovary (Gk. *epi* upon). The epigynous condition may also arise from the sinking of the pistil into the receptacle, whereby the sepals, petals, and stamens are again placed on top of the ovary. The hypogynous condition, which is the most primitive, is found in the buttercup and lily, the perigynous in the pea and rose, and the epigynous in the daisy and iris.

Pollination.

When the pollen of a flower reaches the stigma of the same flower or of a flower of the same species, pollination takes place. In the former case we have self-pollination, and in the latter cross-pollination. When we examine a great number of different flowers, and find the numerous structures and arrangements

existing to prevent self and ensure cross-pollination, we come to the conclusion that the latter has some special advantage over the former. There is always a possible advantage in having two parents instead of only one, as would be the case in self-pollination. The offspring in the latter case would reproduce very closely the constitution and peculiarities of the parent plant, and variations would be slight and infrequent. Where, however, the pollen is brought from the anthers of one flower to the stigma of another the offspring, having two parents, may show considerable variation from both. Its characteristics will be a mixture of those of its ancestors. In some instances, the new plant will produce the weak points of both parents, in which case it will be eliminated in the struggle for existence, in others again it will combine some of the strong and some of the weak points of both; and here, too, it will, though after a longer time, also be eliminated: finally there will now and then arise individuals which combine most of the strong points of one parent with the strong points of the other, and these are the plants that will eventually oust all competitors and obtain possession of the earth. It must be remembered that when we speak of **strong points** we mean those features that specially adapt the plant to its own particular environment.

Darwin made a number of experiments to determine the advantage of cross-pollination. He found that in certain plants growing close together cross-pollination secured in the offspring an advantage of 30 per cent. in vigour and productiveness over those resulting from self-pollination, and that, when this was carried on to the tenth generation, the advantage was increased to 50 per cent. By bringing pollen from a distant garden, even higher percentages were obtained. It is alleged that there are some flowers that are not fertile to their own pollen, but recent investigations

seem to show that this is probably not absolutely true. The most that can with certainty be said is that in many plants cross-pollination produces a better crop of seeds and enhances the vigour of the offspring. It is obvious that there are two varieties of cross-pollination, first where the pollen of one flower reaches the stigma of another flower on the same plant, and next where the pollen reaches the stigma of a flower on a different plant. The primrose seems to need the latter kind, though in most plants there is but little diminution in vigour if the former is effected.

Self-pollination is effected in a great number of common plants. Wheat flourishes when subjected to it, and many common weeds, such as wire-weed or common knot-grass, chickweed, and mallow constantly make use of it. The flowers of the geranium are generally self-pollinated, while, in the evening primrose, though cross-pollination is the rule, self-pollination often takes place, even before the flowers open. **Cleistogamic** or **Cleistogamous** (Gk. *cleistos* shut and *gamos* a marriage) flowers are those in which self-pollination takes place within the unopened bud. In the violet, a few weeks after it has apparently done flowering, there is produced a fresh crop of small colourless flowers borne on short stalks near the ground, or, in some cases, even underground. These cleistogamous flowers never open but still produce fruit and seed. The petals, being no longer needed for the attraction of insects, almost disappear, and the anthers are so placed that they come into contact with the stigma as soon as it is ripe. In the thread-like violet of New Zealand (*Viola filicaulis*), about January small cleistogamic flowers are produced on short stalks less than an inch long. The style, which is as long as usual, is coiled on top of the ovary so that the stigma may come into contact with the anthers. It is a rare thing for orchids to be self-pollinated, but in

thelymitra (*maikaika*), a common native genus, self-pollination must often take place. Indeed, in the South Island the flower is almost always cleistogamic. It rarely opens, but almost invariably produces fruit. The cleistogamic condition doubtless serves to protect the pollen, which is reduced by rain to a useless pulpy mass. The flower limosella, a native plant of the snapdragon family, which grows in rain-pools, is cleistogamous if submerged, the perianth forming a water-tight envelope, under cover of which pollination takes place. Cleistogamy is evidently a protective adaptation that has helped some plants to survive in the struggle for existence, especially in a moisture-laden atmosphere.

Cross-pollination takes place where the stigma of a flower receives the pollen from another flower borne either on the same plant or on a plant of the same species.

In **diclinous** plants, *i.e.*, those in which stamens and pistil are borne on different flowers, cross-pollination is a necessity. Diclinous (Gk. *di* two) plants are of two kinds, **monœcious** (Gk. *monos* single and *oikos* a house), where, as in the vegetable marrow and many pines, both pistillate and staminate flowers are borne on the same plant; and **diœcious**, where, as in the native clematis and pepper (*kawakawa*), they are on different plants. The New Zealand flora is remarkable for its large number of dioecious plants belonging to a great variety of orders. For instance, the toa-toa, or celery-leaved pine, the mahoe, a tree belonging to the violet family, the coprosma, one of the coffee family, as well as the lawyer, pepper, and clematis are all dioecious.

There is another device by which self-pollination is prevented and cross-pollination made a necessity. One essential organ may mature before the other. Where the anthers ripen and shed their pollen before the

stigma is ready to receive it, as is the case with the Canterbury bell and daisy families, the flower is said to be **protandrous.** The little blue bell (*Wahlenbergia*), so common in wild places throughout New Zealand, is of this type. It may, however, be mentioned that, in both these families, if cross-pollination fails, self-pollination is effected by the coiling of the split style in such a way as to bring the stigma into contact with the pollen that clings to its outer surface. Where the stigma ripens first, as in the plantain and arum, the flower is **protogynous.**

The third means by which self-pollination may be prevented is the **arrangement** of stamens and pistil in such a way that pollen from the former cannot reach the stigma. In such cases there is, of necessity, a special mechanism or arrangement, whereby cross-pollination by external agency is facilitated. So far, the discussion has dealt almost exclusively with the prevention of self-pollination. It will now be necessary to show by what means cross-pollination is effected.

Wind is one of the great carriers of pollen, as is well seen in all pines and grasses. These produce great quantities of dry dust-like pollen, which, at certain seasons, fills the air, in the latter case to such an extent as to give rise to the complaint known as hay fever. Flowers that are wind-pollinated are usually small and inconspicuous, have long feathery stigmas and long stamens hanging well out of the corolla, as a rule are without perfume, and do not secrete nectar. These characteristics might be expected. They eliminate the useless expenditure of energy on the unnecessary attraction of insects, but are well adapted for the receiving and dispersal of pollen. The coprosma and piri-piri (bidi-bidi) are among the commonest and most typical of the native wind-pollinated plants.

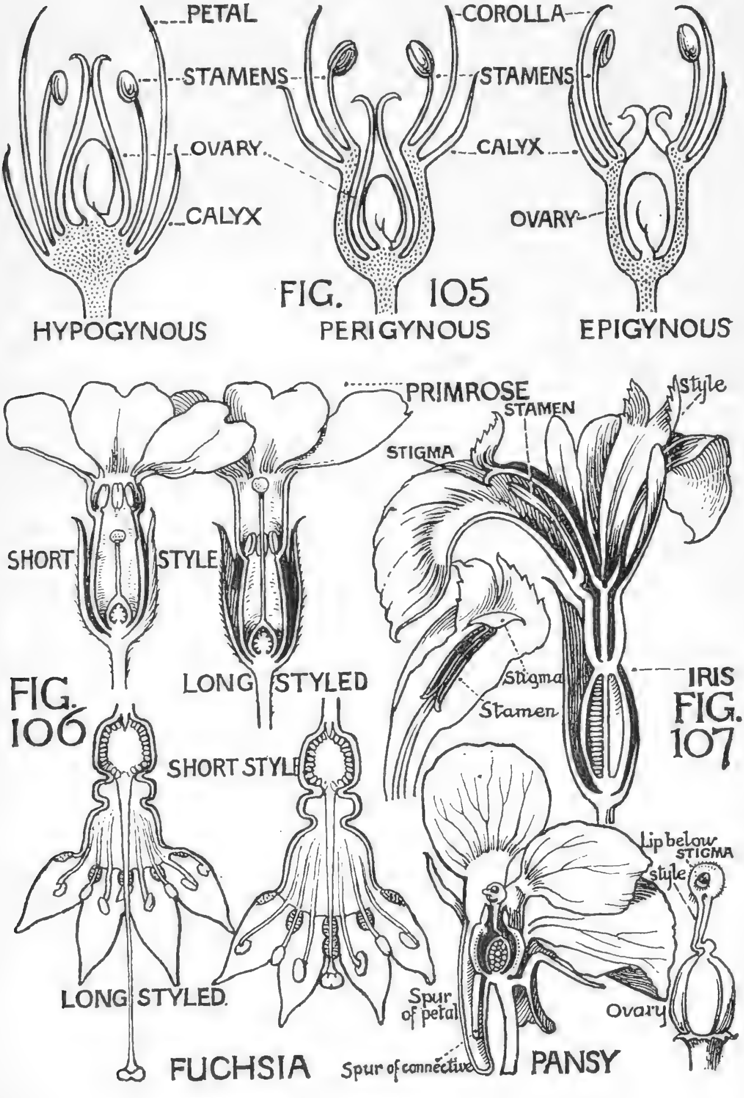
Insects are the chief agents of cross-pollination. Among the myriad mechanisms for preventing self and

effecting cross-pollination it will be possible to mention only a few.

1. In the **pea** family, to which the bean also belongs, the flower is so placed that a bee visiting it must alight on the wings. The weight of the bee depresses the wings, which drag down the keel with them. This exposes the stigma and stamens. First the stigma at the end of the bent style strikes the insect on the under side of the body. Then the stamens come into contact with the same part. Without again touching the stigma, the insect flies away. Thus it does not effect self-pollination. On visiting another flower, again it is struck first by the stigma, which receives the pollen brought from the first flower: thus cross-pollination is effected.

2. In the **primrose** (Fig. 106) we have the condition called **dimorphism** (Gk. *di* two and *morphe* shape), *i.e.*, there are two forms of flower. In one, known as the pin-eyed form, the style is long and the stigma, which forms at the tip a body much like a pin's head, protrudes from the corolla tube. The anthers in this form are attached to the inside of the tube about half-way down. In the thrum-eyed form the positions are reversed: the anthers are at the mouth of the corolla tube, while the stigma reaches about half-way up or is in the same position as the anthers were in the pin-eyed form. A bee, pushing into a flower with short stamens, gets the pollen on its tongue, which it thrusts down for the nectar secreted at the base of the ovary. On now visiting a thrum-eyed flower, the insect naturally transfers to its stigma the pollen brought from the first flower, for here the stigma is at the same height as were the stamens in the pin-eyed form. In visiting a thrum-eyed flower the insect gets the pollen on its head, a position exactly suited for its transfer to the stigma of a pin-eyed flower. In the primrose, in cases where a thrum-eyed or pin-eyed flower is fertilized by

FLOWER AND POLLINATION



its own pollen, a very poor development of seed and fruit takes place.

The New Zealand **fuchsia** has at least three forms (F. 106).

(*a*) In the **long-styled** form, the style is more than twice as long as the calyx tube. In this form the stamens are practically sessile on the calyx tube with but poorly developed pollen. This is to all intents a female flower.

(*b*) In the **mid-styled** form the anthers have long filaments, which are, however, shorter than the style. The pollen is deep blue.

(*c*) In the **short-styled** form the filaments are about the same length as the style, and the pollen is again deep blue.

It is practically certain that this variety of form serves some useful purpose in connection with pollination, which under natural conditions, is carried out by tuis and other nectar-loving birds. What this may be has not yet been discovered.

3. In the **iris** (Fig. 107) the stamen, which dehisces outwards, is protected under a kind of hood formed by the petaloid style. Just beyond the tip of this stamen, on the upper side of a flap hanging from the style, is the stigma. An insect pushes its way into the flower between the style and one of the lobes of the perianth. In so doing, it first brushes against the stigma on the upper side of the flap. On pushing further in, it brushes its head and back against the anther and so becomes dusted with pollen. On backing out of the flower it closes up the flap, so that the stigma is prevented from receiving any of the pollen with which the insect is laden. In this way, self pollination is prevented. While pushing its way into another flower it again brushes against the stigma and cross pollination is effected.

4. In the **pansy** (Fig. 107) the stigma is near the top of the style in a depression below which protrudes horizontally a little shutter or flap. The bee alights on the front petal, and to secure the nectar thrusts its tongue into the spur of the petal where, on prolongations of the anther connectives, the nectaries lie. In so doing, the insect first pushes against the upper side of the shutter. Its tongue then passes down, picking up some of the pollen which is shed into the spur. On withdrawing its tongue the bee closes the shutter upwards against the stigma so that the latter is protected from self-pollination. On pushing into another flower it deposits the pollen from the first on the upper side of the shutter. When the insect withdraws, the shutter is again pushed upwards and the pollen upon it deposited on the stigma. Thus cross-pollination takes place.

5. In the **salvia** (Fig. 108) there are two stamens, each bearing only one anther lobe. The connective is greatly prolonged and terminates on the lower end in a large flattened body. The bee in pushing into the flower presses against this flattened body. The whole mechanism acts as a kind of lever with the tip of the filament as the fulcrum. The pressure against the flattened body causes the anther lobe, which is situated at the end of the other arm of the lever, to be depressed and strike the insect's back, which, in consequence, becomes dusted with pollen. The insect withdraws from the flower without touching the stigma. In more mature flowers the style curves down, so that an insect visiting such a flower brings its back into contact with the stigma, and thus effects cross-pollination.

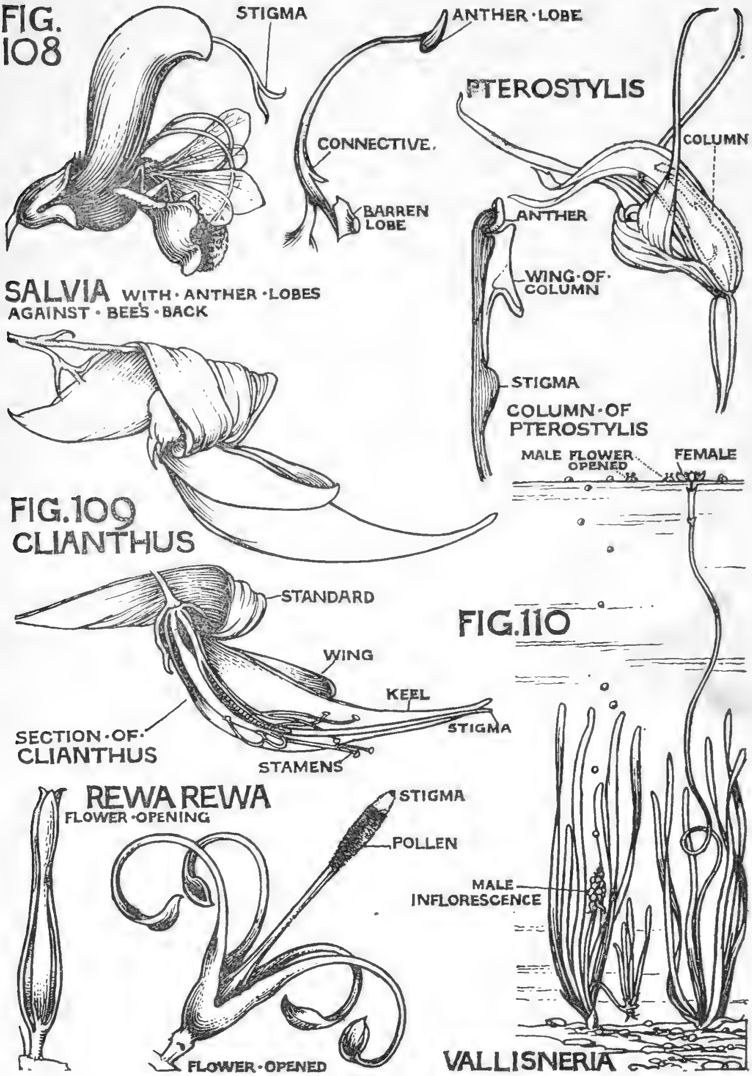
6. It is among **orchids** that the most marvellous pollination mechanisms are found. In the different New Zealand species there is nothing very remarkable, but the pollination of Pterostylis (Fig. 109), so well described by Mr. Cheeseman, is worth careful study

wherever the flower is available. An insect entering the flower is, by the narrow front petal which acts on a kind of spring, shut up against the column, the upright body in the interior of the flower, formed by the fusion of the andrœcium and gynœcium. It can escape only by crawling up between the wings of the column. In so doing it comes first into contact with the stigma and then, on emerging, brushes against the anther and carries off the pollen masses on its back. On visiting another flower it deposits some or all of the pollen on the stigma.

7. The pollination of the **yucca** is one of the most marvellous things in nature. The female of the moth *pronuba,* which lives in the flower, collects from the anthers a considerable mass of pollen. She then thrusts her egg-laying tube (ovipositor) into the ovary of the flower and deposits an egg. Finally she passes to the stigma and thrusts into it the pollen she has gathered. In this way pollination (not cross-pollination it will be noted) takes place, and the ovules of the flower develop, some of them serving the larva of the moth with food till it bores its way out of the fruit. Thus *pronuba* and the yucca are mutually useful. *Pronuba* provides for fertilization, and thus secures the development of the yucca's seed; while the yucca, at the sacrifice of a portion of its seeds, supplies *pronuba's* offspring with food.

Unsuitable Insects.—Besides attracting insects and providing a mechanism for cross-pollination, flowers must also protect themselves against the visits of unsuitable insects; otherwise they may be robbed of their nectar and pollen and yet remain unpollinated. Ants, for instance, are fond of sweet food, but, as they walk from flower to flower and plant to plant, there is danger of the pollen being brushed off. The most suitable insects are butterflies, moths, bees, and other insects that fly from flower to flower. The following

POLLINATION



are some of the means by which the visits of unsuitable insects are prevented:—

1. **Isolation.**—The bladderwort (*Utricularia*) flower floats on the surface of the water, so that none but flying insects can reach it.

2. **Sticky juices,** secreted at each node of the stem in certain species of catchfly, prevent creeping insects from reaching the flower.

3. **Hairs** in the salvia, act as a barrier to insects that would not be strong enough to work the lever. A hairy stem may serve the same purpose.

4. The **structure** of the flower in some cases prevents the entrance of any but an insect large enough to do the work of pollination. In the snapdragon, for instance, it requires a heavy insect to depress the lower lip sufficiently to open a way into the flower.

5. **Closure** during the hours of light protects the flower of the evening primrose against many creeping insects that are abroad in the daytime.

Animals other than insects, as for instance, slugs and birds, also pollinate flowers, as was seen in the case of the fuchsia.

1. In the **clianthus** (*kaka-beak*), the so-called red kowhai, the tui was originally the chief agent of pollination. On thrusting his tongue to the base of the keel, into which the pollen had been shed, he would cause the brush-like style to sweep out the pollen on to his forehead. The stigma, which is at the end of the style, would, however, first strike the bird, so that it would receive pollen that might have been brought from another flower.

2. The **rewarewa** (*Knightia excelsa*) (Fig. 109), under natural conditions, is pollinated by tuis and other native birds. The anthers are pressed close against vertical grooves towards the top of the style. Into these grooves the pollen is shed, being well protected by the perianth tube, which does not open till

the pollen is ready for use. The different stages in the opening of this flower are most peculiar, but, so far as can be learned, have no direct bearing on its pollination. First the perianth tube opens at the tip to expose the apex of the style, where the stigma, lying in a small depression, is not yet ready to receive the pollen. Next, longitudinal splits appear near the base of the tube, and finally the whole perianth splits into four segments which curl back. Thus the inflorescence, which bears a considerable number of flowers, forms, when mature, a tangled mass of perianth lobes. The tuis, thrusting their tongues among the now exposed styles, get the pollen dusted on their heads, and may carry it to other flowers in which the stigma has arrived at the receptive stage. In this way cross-pollination is effected.

Water is, in some rare instances, the agent of pollination. This is the case with vallisneria (Fig. 110), the male plant of which is so plentiful in Lake Takapuna, where, beginning as a tiny shoot, it has vegetatively reproduced till it is a serious impediment to the use of boats upon the lake. The plant is diœcious. The stem having the pistillate flower rises to the surface where the flower opens and displays its stigmas. The staminate flower, however, is produced below the water at the end of a short stalk. Before the buds expand they break off and rise to the surface, where they open and expose their stamens. These, floating on the surface, may come into contact with pistillate flowers and thus bring about cross-pollination, which, of course, seeing that the plant is diœcious, is the only kind possible.

Inflorescences.

Mention has been made of the advantage for insect attraction possessed by a showy flower. Where such flowers are collected in groups, this advantage is

intensified. For wind-pollination, too, the massing together of flowers is an advantage; for, when the stigmas are clustered in groups, as is the case with the maize, there is a better chance of their arresting the pollen grains than if they were arranged singly. Moreover, in the latter case, to adequately display the flowers, more energy must be expended on the production of the flower stalks.

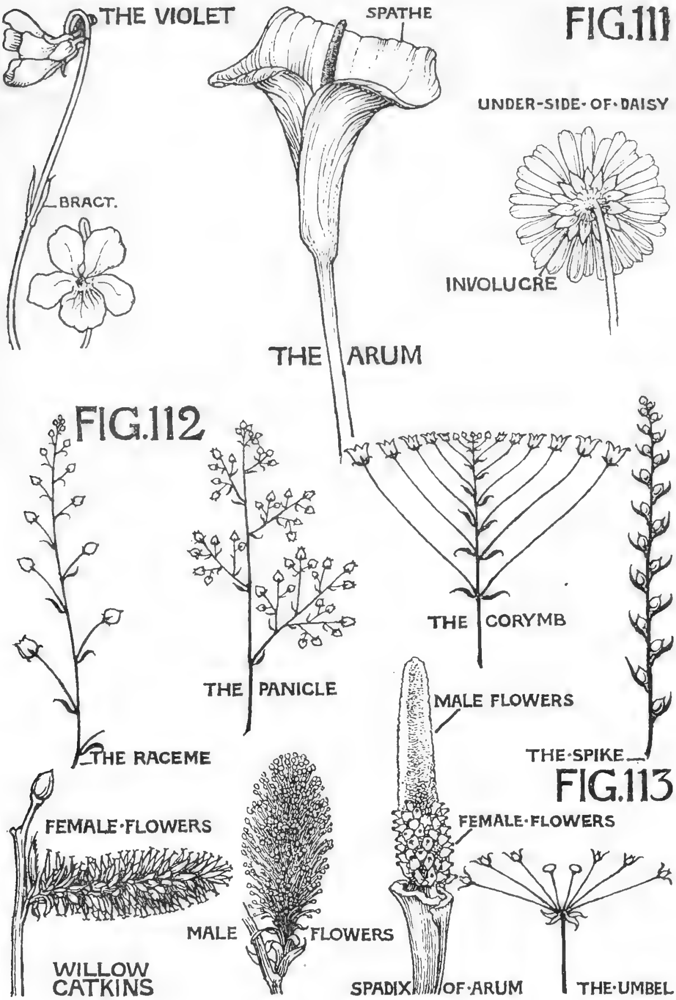
The term **inflorescence** denotes the grouping and arrangement of the flowers produced on any one floral axis. The main stalk of an inflorescence is usually called the **peduncle**, but where it forms an unbranched leafless axis arising from the midst of radical leaves (*i.e.*, leaves springing from the ground) and bears flowers at its apex, as in the cowslip, it is known as a **scape.** The stems of individual flowers in an inflorescence producing more than a single flower are termed **pedicels.**

Bracts (Fig. 111) are modified leaves, which, when present, usually protect the flowers of an inflorescence while in the bud. In the violet a small bract springs from either side of the peduncle. In the arum a large white flower-like bract known as a **spathe** protects the spike-like inflorescence within. The dandelion and most other members of the daisy family have a ring of bracts forming what is called an **involucre,** situated immediately below the inflorescence.

Forms of Inflorescence. Inflorescences may be either definite or indefinite, the latter being by far the commoner.

In an **indefinite** inflorescence (Figs. 112-113A) the youngest flowers and buds are at the end of the peduncle. Those produced nearer the base open first, and there is an indefinite succession of blooms, each produced nearer the tip than the one that opened before it. In other words, the flowers are produced in **acropetal** (Gk. *akros* apex and *peto* I seek) succession.

BRACTS AND INDEFINITE INFLORESCENCES



1. The **raceme** is the commonest indefinite inflorescence. The flowers, as in the foxglove and towai (*Weinmannia racemosa*), are arranged singly on pedicels along a central peduncle.

2. **Panicle**. Where the flowering axis is branched, as in the cabbage tree (*Cordyline*) and the oat, the inflorescence is a panicle.

3. A **corymb** differs from a raceme in the fact that the pedicels of the lower flowers are lengthened to bring all the flowers to the same level, and so form a flat surface suitable for an insect to walk upon. This form of inflorescence is well seen in the candytuft, and appears in some of the native species of cardamine.

4. The **spike** is like a raceme in which the pedicels have disappeared, the flowers all being sessile on the peduncle. This is well seen in the plantains both native and introduced.

5. A **catkin** differs from a spike in being unisexual. Male flowers are sessile on one flowering axis and female on another, which may be on the same plant, as in the hazel, or on another plant as in the willow and kawakawa (*Piper excelsum*).

6. The **spadix** is seen in the arum. Small male flowers are situated on the upper, and female flowers on the lower part of the fleshy axis. It is like the body that would be formed by the union of two catkins with the male above.

7. **Umbel**. In an umbel, the flowers all spring from the apex of the peduncle, the pedicels meeting at that point. This is well seen in the cowslip. The compound umbel appears in the panax as well as the parsnip, carrot and most members of that family.

8. **Head**. In the head or capitulum the end of the peduncle carries a broad flattened receptacle on which are situated numerous sessile flowers. This is seen in the daisy, clover and piri-piri (*bidi-bidi*). What is popularly regarded as the flower is really an inflor-

FIG. 113A
Fruiting head of piri-piri
(Acaena sanguisorbae)

escence, consisting of a great number of flowers or florets massed together.

Relationships.—The raceme is probably the primitive form of inflorescence. The panicle may be regarded as a branched raceme; the corymb as a raceme in which the pedicels of the lower flowers have lengthened; a spike as one in which the pedicels have disappeared; a catkin one in which, not only have the pedicels disappeared, but the flowers of certain inflorescences have lost their male, while those of others have lost their female organs; the spadix one in which a similar thing has happened but on the same inflorescence; an umbel one in which the internode-like intervals of the penduncle have disappeared, and all the flowers have been brought to the same level; and finally, a head is the same thing as an umbel in which the flowers have become sessile.

A **definite** inflorescence (Fig. 114) is one in which the flower at the end of the axis opens first, the next flower, where present, being produced by the branching of the peduncle below the first, the third by a branch produced from the first branch below the second flower, and so on till the flowering capacity of the shoot is exhausted. This will best be understood by consulting the diagrams. The following are the chief definite inflorescences:—

1. **Solitary.** This arises when the main axis produces at its end a single flower and there is no branching whatever. This is well seen in the tulip and tea-tree. In the latter the solitary inflorescence may be terminal, at the ends of short branches, or axillary, in the axils of the leaves.

2. **Cymose** inflorescences are definite inflorescences that branch as indicated above. The branches may be

produced on both sides of the main axis as in the buttercup, or only on one side as in the forget-me-not. A **verticillaster** is a cymose inflorescence seen in pennyroyal and self-heal. Small cymes, each of from three to five flowers, are massed together in rings in the axils

DEFINITE INFLORESCENCES

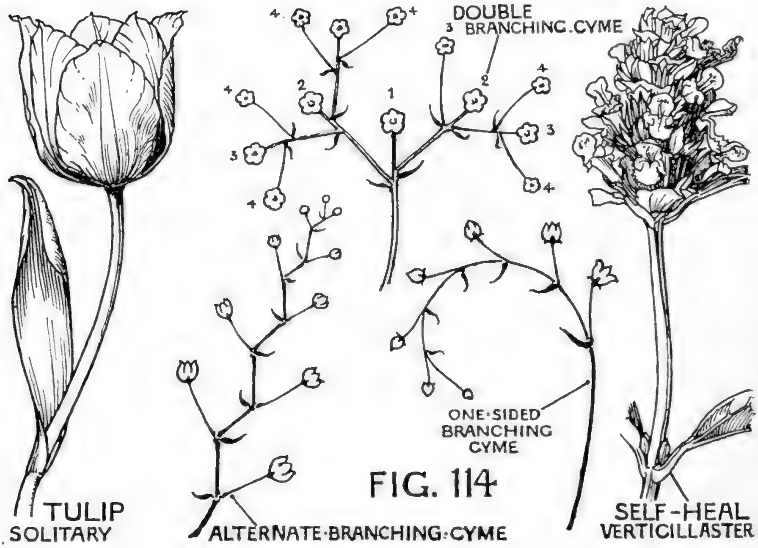


FIG. 114

of bract-like leaves, in the case of the self-heal producing the appearance of a short thick spike.

The Fruit.

If, as was suggested, the study of the natural orders and practice in plant description have gone hand in hand with the investigation of separate organs, the student should now be familiar with various types of fruits. This section will therefore be devoted merely to the arrangement and classification of the different forms.

A **fruit** is the body produced by the development of the ovary and surrounding parts as a result of fertilisation. The ovules become the seeds and the wall of the ovary becomes the wall of the fruit, which may remain succulent or become dry and hard. The great functions of the fruit are to protect the seed and provide for its distribution.

Fruits may be simple, aggregate or composite, simple fruits being derived from a single carpel or a number of united carpels, aggregate fruits from a number of free carpels, and composite fruits, not from a single flower but from an inflorescence. **Simple** fruits may be either dry or succulent, and dry simple fruits may be either dehiscent or indehiscent, *i.e.*, they may or may not open to let out their seeds.

The **achene** (Fig. 115) is the type of the dry indehiscent form of simple fruits. It is formed from a one-seeded superior ovary derived from a single carpel, the pericarp (ovary wall) and testa are free from each other, and both are ruptured by the escaping embryo. This is well seen in the dock and sorrel, and in the individual members of the aggregate fruits of the buttercup and clematis. The following fruits are similar to achenes:—

1. The **cypsela** is the characteristic fruit of the daisy family, and differs from the true achene in being formed from an inferior ovary derived from two united carpels. Its origin rather than its form constitutes the difference.

2. The **caryopsis** is well seen in the wheat and maize grains and the fruits of all other grasses. It differs from the achene in having the testa and pericarp (*i.e.*, the seed coat and seed case or ovary wall) fused together.

3. The **samara** is a winged achene well seen in the ash, elm, and ake-ake (*Dodonœa*).

DRY FRUITS

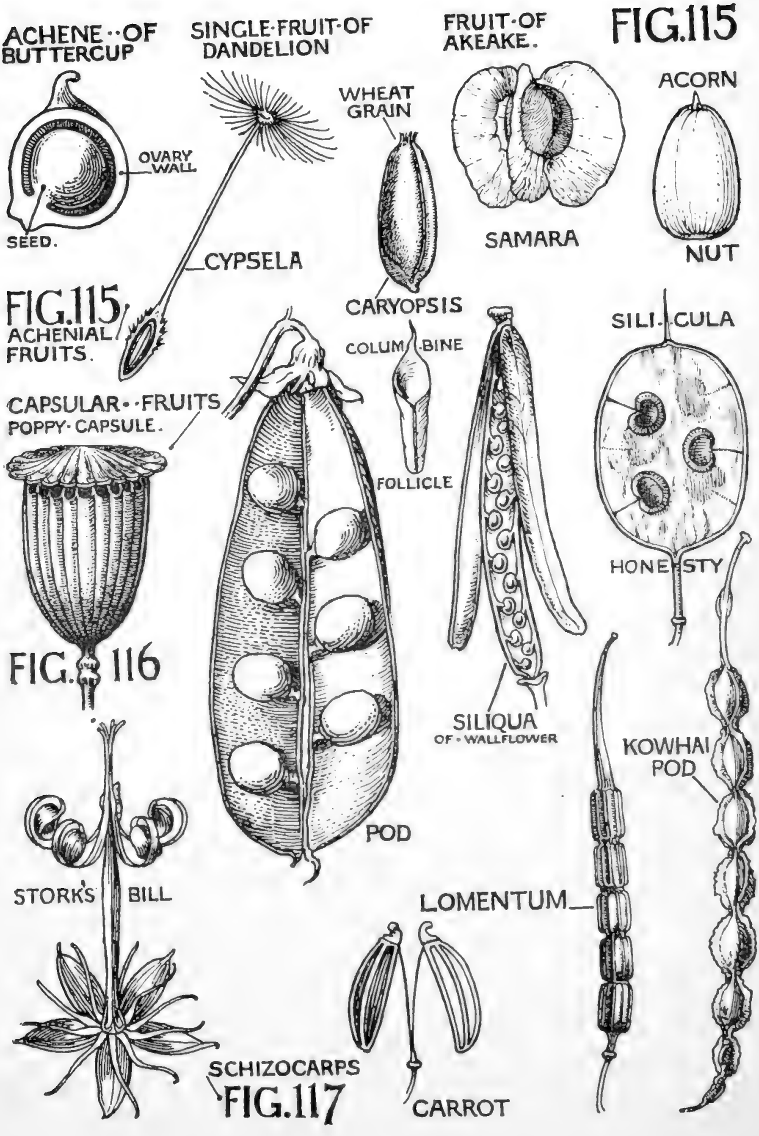


FIG.115
ACHENE OF BUTTERCUP
OVARY WALL
SEED.
SINGLE·FRUIT·OF DANDELION
CYPSELA
WHEAT GRAIN
CARYOPSIS
FRUIT·OF AKEAKE.
SAMARA
ACORN
NUT
FIG.115 ACHENIAL FRUITS.
CAPSULAR FRUITS
POPPY·CAPSULE.
FIG. 116
COLUMBINE
FOLLICLE
SILIQUA OF·WALLFLOWER
SILICULA
HONESTY
POD
KOWHAI POD
LOMENTUM
STORK'S BILL
SCHIZOCARPS
FIG.117
CARROT

4. The **nut**, as in the hazel, oak, and tawhai or native beech (usually alluded to as birch) has a hard woody pericarp forming a shell. The coconut, brazil nut, and walnut, as will be seen later, are not nuts at all.

The **capsule** (Fig. 116) is typical of dry dehiscent fruits. It is formed from several united carpels, and may be one-chambered, as in the violet and orchid, or several-chambered, as in the lily. The following fruits are after the nature of capsules:—

1. A **legume** or pod, seen in the bean, pea, and kowhai, is a one-celled fruit formed from a superior ovary derived from a single carpel. The seeds are along the ventral suture, and the fruit dehisces along both ventral and dorsal sutures.

2. The **follicle** is like a pod, except that it splits along the ventral suture only. This is seen in the individual members of the aggregate fruits of the columbine and in the rewarewa (*Knightia*).

3. The **siliqua** is the characteristic fruit of the wall-flower and turnip family. It is formed from a superior ovary derived from two carpels which have united by their edges. The fruit is two-celled owing to an ingrowth from the placentæ forming a septum. The fact that the ovules have not been carried in by this ingrowth shows that the septum is not due to the infolding of the carpellary leaves. It is therefore called a false septum. This fruit dehisces by the breaking away of the carpellary leaves, the seeds remaining attached to the placentæ at the margins of the false septum.

4. A **silicula** is of the same nature as the siliqua but is shorter, broader, and flatter. This is seen in honesty and shepherd's purse.

Schizocarps (Gk. *schizo* I split, and *karpos* fruit), are dry fruits (Fig. 117) that split up into a number of dry, one-seeded, generally indehiscent fruits resembling achenes. Such fruits are those of the

wharangi (*Melicope*), the geranium, parsnip, and mallow. The double samara of the sycamore is also a schizocarp.

The fruit of the kowhai shows how schizocarps may be formed. The pod is constricted at intervals. If these constrictions resulted in the fruit breaking into one-seeded pieces, as in the radish, we should have a **lomentum.**

Succulent simple fruits (Fig. 118) have a soft fleshy pericarp. The following are the chief types:—

1. The **drupe** is well exhibited in the plum, cherry, apricot, karaka, and coprosma. The **pericarp** of a drupe consists of three layers: an **epicarp** (Gk. *epi* upon) or skin on the outside, a **mesocarp** (Gk. *mesos* the middle) of soft material, and an **endocarp** (Gk. *endo* within) of hard stony material enclosing the seed. A walnut and a coconut are both drupes. On the outside is the skin, and inside this, in the walnut a fleshy, and in the coconut a fibrous, mesocarp. In both cases, before the fruit is put on the market, the skin and mesocarp are removed, and what is sold is in each case really the stone of the fruit, *i.e.*, the endocarp and seed.

2. The **berry** is succulent and pulpy throughout its pericarp, and the seeds are scattered in the pulpy mass. This is well seen in the grape, gooseberry, orange, tomato, cucumber, tawa, and poroporo, called by the settlers the bullibulli (*Solanum aviculare*). The date is a berry, for, as we have already seen, the stone is not endocarp but endosperm. The banana is a berry from which seeds have been eliminated by selection.

3. In the **pome** as shown in the apple, medlar, and hawthorn, the calyx tube and receptacle, becoming very fleshy, grow up round the carpels, enclosing and fusing with them. The remains of the sepal lobes are seen at the summit of the fruit. The core of the apple is derived from the carpels and is the true pericarp

FRUITS

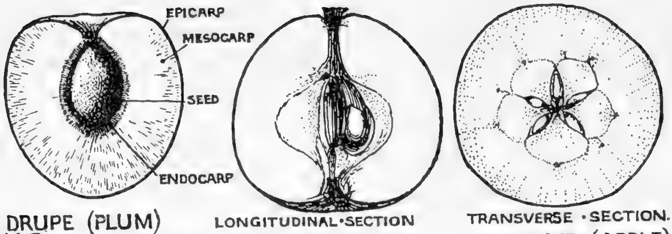


FIG.118 SIMPLE·SUCCULENT·FRUITS.

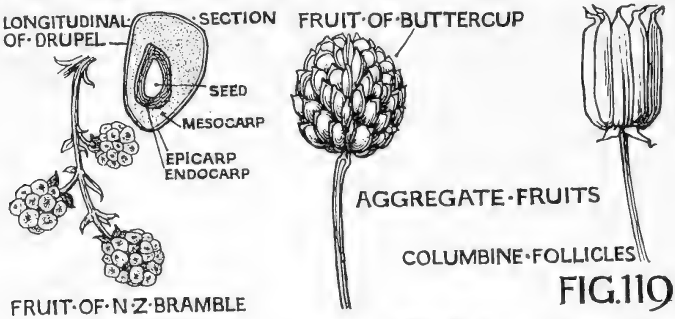


FIG.119

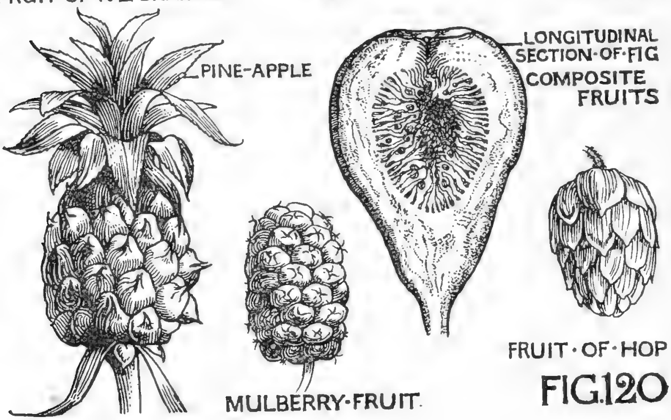


FIG.120

enclosing the seeds. In the hawthorn, however, the carpels become stony.

Aggregate fruits (Fig. 119), derived from a number of free carpels and consisting of a number of separate fruitlets, are called **etarios**. They may be either dry or succulent.

1. The buttercup fruit is an etario of **achenes**. The strawberry, is also an etario of achenes, the small fruits popularly called the seeds, being scattered over the swollen fleshy receptacle, which forms the bulk of the fruit. The fruit of the brier consists of an etario of achenes enclosed in a fleshy receptacle and calyx tube.

2. The fruit of the larkspur and columbine are etarios of **follicles.**

3. Etarios of **drupelets** (little drupes) are seen in the raspberry, blackberry, and lawyer.

Composite Fruits (Fig. 120) are formed from inflorescences. Such is the case with the pineapple, mulberry, fig, and hop.

Protection is afforded to fruits in various ways. The chestnut and thorn apple (*Datura*) are guarded by their spines, the dock and all nuts by their hard coverings. Peas are suspended on slender stalks, and are thus rendered immune from the attacks of mice, while the fruit of the peanut, being buried underground, is concealed from most of its enemies. The acrid taste of green garden fruit successfully wards off the depredations of birds, but not those of many eating insects.

Seed Dispersal.

The protective function of the fruit is obvious and requires no comment, but the work done by the fruit in seed distribution is more varied and complicated. It is of great advantage to a plant to have its seed well distributed over a large area. In the first place a change of soil and situation is usually beneficial. Then

again some of the seeds may fall in situations more favourable to their development than that occupied by the parent plant. Moreover, when well distributed, the seeds get away from the shade of the plant that bore them and into new soil that has not been exhausted of the particular minerals they need, and at the same time crowding of the seedlings is obviated. In short, where seeds are widely scattered there are numerous possibilities. Many may fall in places altogether unsuitable for their development, but there is always the chance that one or more among thousands may light on the ideal environment and become the progenitors of a long line of stalwart descendants. Plants, then, which have an efficient means of seed dispersal have a considerable advantage in the struggle for existence.

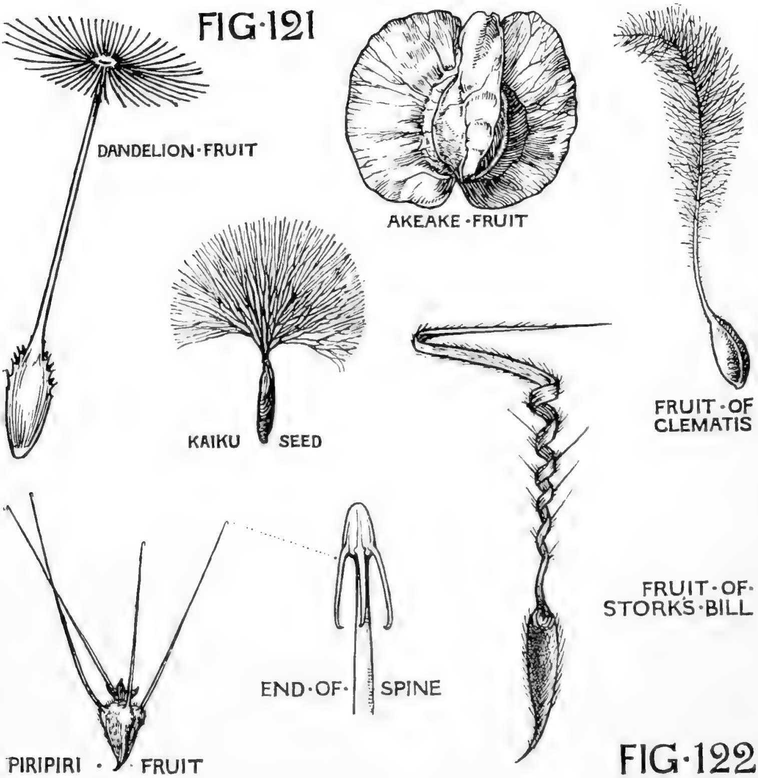
Wind, water, and animals are the chief agents of seed distribution, though fruits themselves may possess mechanisms which independently serve the same purpose.

1. **Wind** is the chief agent (Fig. 121). Many seeds such as those of orchids, being very small and dust-like, may be carried great distances by the wind. The dandelion fruit, as well as the fruit of many of the senecios so plentiful in New Zealand, are distributed by the assistance of a modified calyx which forms a pappus or tuft of hairs that greatly increases their buoyancy. In the willow and kaiku (*Parsonsia*) the tuft of hair is on the seed which escapes from the fruit.

The fruit of the ake-ake, ash, and elm have membranous wings that also provide for wind distribution. The feathery style of the clematis serves the same purpose. In the silvery sand-grass (*Spinifex hirsutus*) the whole inflorescence may, in its season, be seen tumbling along the beach, for this is its way of distributing its seed.

2. **Water** is another great seed-distributer. Some fruits, such as that of the coconut, can remain in salt water for considerable periods. The coconut floats

SEED DISPERSAL



FIG·121

FIG·122

from island to island, and in this way the palm has been spread throughout the Pacific. In the water-lily, the seed is enabled to float to a considerable distance by means of a spongy aril that contains air. The kowhai is commonly distributed by water, its air-tight

pod carrying the seeds long distances. That prolonged soaking, even in salt water, does not appreciably impair the germinating power of the kowhai seed may be proved by experiment.

3. **Animals** distribute seeds in two ways. Barbed, spiny, or rough-coated fruits may cling to their coats (Fig. 122). This is the case with the piripiri, in which a barbed spine springs from the base of each of the calyx lobes. The Bathurst burr, dock, and uncinia are distributed in the same way. The pittosporum fruit is full of mucilage, which causes it to adhere to an animal's coat and thus facilitates its dispersal. Birds and other animals eat many succulent fruits, such as those of the cherry, coprosma, and ink plant, and, passing the seeds undigested through their intestines, spread them over a large area.

4. **Explosive** fruits exist, which, on opening, expel their seeds to considerable distances. Such are the gorse, violet, and balsam. On approaching a gorse thicket when the pods are ripe one hears a constant snapping noise, which is produced by the dehiscence of the fruit.

5. **Hygroscopic** (Gk. *hygros* moist, and *skopeo* I see) movements, *i.e.*, movements due to the absorption of water, serve to distribute some seeds. The schizocarp of stork's bill (*Erodium*) (Fig. 122) breaks up into five long bodies. Each of these, when dry, forms a coil. When it becomes wet it straightens out, and, on becoming dry, coils once more. By thus alternately coiling and uncoiling it travels over the ground. These movements also serve to bury the seed.

Summary.

The **flower** is the reproductive organ. The **sepals** form the **calyx.** They may be **aposepalous** (free) or **synsepalous** (united). They protect the essential organs against rain, cold, and evaporation.

Petals and **sepals** together form the **perianth,** petals alone the **corolla.** Petals are chiefly to attract insects but may also be protective. They may be **apopetalous** (free) or **synpetalous** (united). A regular flower is **actinomorphic,** an irregular one **zygomorphic.** Flowers **attract** insects by their size, shape, colour, nectar, and perfume. Petals may protect the pollen by arching over it or by closing.

Essential Parts.—The stamens form the **andrœcium,** the carpels the **gynœcium.** The stamens may be united or free. The stamen consists of **filament** or stalk and **anther** with **pollen sacs** containing pollen. Dehiscence may be **introrse** (inwards) or **extrorse** (outwards).

The **gynœcium.**—The term pistil and gynœcium are synonymous where there is only one carpel, or the carpels are united. When there is a number of free carpels each carpel is a separate pistil. Each pistil has an **ovary** containing **ovules** and a **style** lifting up the **stigma** or receptive part. The gynœcium may be **syncarpous** or **apocarpous.** The ovary may be one or many celled. **Placentation** of the ovules may be **parietal, axile, free central, basal,** or **suspended.**

Pollination takes place when the pollen grain reaches the stigma; **fertilization** when the pollen **nucleus** reaches the **egg-cell** of the ovule.

Nectaries are gland-like structures that secrete nectar. Honey guides may show the way to these.

Cohesion refers to the union of the members of the same whorl; **adhesion** to the union of members of different whorls. The normal arrangement is **hypogynous,** with calyx lowest on the receptacle, corolla next, stamens next, and carpels next. In a **perigynous** flower the petals and stamens are lifted up on the receptacle, which forms a cup round the ovary. In an **epigynous** flower the sepals, petals and stamens are on top of the ovary. Stamens are sometimes **epipetalous.**

Pollination may be either **self** or **cross.** Cross pollination is an advantage. Self pollination takes place in wheat, wireweed, chickweed, and mallow. **Cleistogamous** flowers must be self pollinated. Cross must take place in **diclinous** (monœcious and diœcious) flowers, as also in **protandrous** and **protogynous** flowers. **Wind** pollinated flowers are inconspicuous, have much fine pollen, and have stamens and stigmas hanging out of the flower. **Insects** are the chief agents. There are numerous floral mechanisms to prevent self and effect cross pollination, *e.g.*, in primrose, pansy, pea, salvia, iris, and orchids. Pronuba pollinates the yucca, and birds the rewa-rewa and clianthus.

Unsuitable insects are kept off by sticky juices, hairs, structure of the flower, and closure.

Water carries the pollen of vallisneria.

An **Inflorescence** comprises all the flowers produced on a single flowering axis. The main axis is the **peduncle,** and the stalks of single flowers on many-flowered inflorescences are **pedicels. Bracts** are modified leaves that protect the flowers of an inflorescence. A **spathe** is a large bract, and an **involucre** a ring of bracts.

The raceme is the commonest **indefinite** inflores-
spadix, umbel, and head. **Definite** inflorescences are
cence. Others are the corymb, panicle, spike, catkin,
either **solitary** or **cymose.**

I. **Simple Fruits**:—

1. Dry and indehiscent—achene, cypsela, caryopsis, samara, nut.
2. Dry and dehiscent—capsule, legume, follicle, siliqua, silicula.
3. Schizocarps, dry, split up into several one seeded indehiscent fruits—lomentum.
4. Succulent—drupe, berry, pome.

II. **Aggregate fruits** or **etarios** — buttercup (achenes), larkspur (follicles), blackberry (drupelets).

III. **Composite fruits** formed from inflorescences—pine-apple, mulberry, hop.

Protection is afforded to fruits by their spines, hard coverings, slender stalks, concealment underground, and, when young, by their acrid taste.

Dispersal of **seed** is an advantage.

1. **Wind** disperses when the seed is light, or where a wing or tuft of hairs is present.
2. **Water** disperses seeds that float and are not injured by soaking.
3. **Animals** distribute seeds that cling to their coats, and also pass seeds undigested.
4. **Explosive** fruits scatter their seeds.
5. **Hygroscopic** movements distribute geranium fruits.

QUESTIONS ON CHAPTER VI.

1. Explain the functions of the different parts of a flower.
2. Describe the position of the nectaries in any four flowers you know, and show how this position is related to the pollination of the flower.
3. Describe four pollination mechanisms you know.
4. Explain the terms hypogynous, perigynous, epigynous.
5. What self-pollinated flowers do you know? What is cleistogamy?
6. Explain the relation of the monœcious and diœcious condition to pollination.
7. What are the characteristics of wind-pollinated flowers? Give examples.
8. How do you account for the white colour of so many New Zealand flowers?
9. Explain the relationship existing among the indefinite inflorescences.
10. What advantage is derived from the arrangement of flowers in heads, umbels, and corymbs?
11. What insects have you observed visiting the pea, salvia, wallflower, pansy, buttercup, and primrose? Where do they alight in each case?

12. Explain the pollination of any New Zealand orchid and of one other native flower.
13. What is the essential difference between a definite and indefinite inflorescence? Explain the relationships existing between the different definite inflorescences.
14. Explain the terms zygomorphic and actinomorphic. Has either form of flower an advantage over the other?
15. What is the floral receptacle? What is meant by the whorls of the flower?
16. Describe the changes that take place in a flower as a result of fertilization.
17. Distinguish pollination and fertilization.
18. Compare the popular or culinary idea of a fruit with the botanical conception.
19. Compare the fruit of a rose with that of a buttercup. Illustrate with drawings.
20. Mention three fruits in which the calyx remains. What purpose might be served by this?
21. Describe fully the fruit of the mulberry, hop, strawberry, apple, plum, pumpkin, in each case detailing the origin and development.
22. What are the chief means of seed-dispersal. Give four examples each of seeds dispersed (*a*) by water, (*b*) by birds, (*c*) by other animals, (*d*) by wind. Give full descriptions.
23. How are seeds protected while ripening?
24. How are the seeds of the piri-piri, flax (*Phormium*), kowhai, akeake, manuka, and blackberry distributed?
25. By means of a table classify fruits.
26. What use is the fruit to a plant?
27. To what classes do the following fruits belong:—Walnut, coconut, almond, wheat grain, pea, wallflower, carrot, pumpkin, tomato?
28. What advantage is gained by a species in which the seeds are widely dispersed?
29. How is it that, in spite of constant weeding, a garden can never be kept absolutely free from weeds?
30. Distinguish monœcious and diœcious plants. Give two or three examples of each from the native flora.
31. What is cleistogamy? Under what circumstances would this be an advantage to the plant?

CHAPTER VII.

THE STRUGGLE FOR EXISTENCE.

Among plants as well as animals there is constant competition for food and place. If a highly cultivated garden be left only for a month or two it will be found that it has been invaded by a growth of hardy, vigorous weeds that have almost choked out the original occupants of the soil. These weeds are merely plants, which, because of certain peculiarities of habit and structure, have an advantage over those they have ousted. The nature of the vegetation covering any uncultivated area depends on the result of the "Struggle for Existence," in which the victory is to the individuals or species whose equipment is best suited to the particular environment. In this struggle, environment exercises a kind of "Natural Selection" resulting in the "Survival of the Fittest" and the "Elimination of the Unfit."

The weight of evidence goes to show that all the variety of plants that to-day covers and beautifies the earth has had its origin in certain extremely simple forms. The small green speck of protoplasm that constitutes the primitive plant has given rise to moss and fern, to grass, shrub, and tree. The earliest one-celled plant multiplied by simple division, a single individual splitting in halves and thus forming two. It might happen, in the course of ages, that, in rare instances, instead of separating, the cells thus formed by division would cohere and produce a two-celled organism. By similar means individuals containing many cells might come into existence. The next step would be when there arose differences in shape and structure of individual cells that formed the organism. If these

differences were useful in the particular environment in which the plants existed, the individuals possessing them would soon oust those not so well equipped and occupy the area, victorious in the "Struggle for Existence." It is to this Struggle, resulting in the "Survival of the Fittest," that the earth owes the diversity of fruits, flowers, and foliage we see around us.

Leaving this record of the past, which is still, in parts, more or less obscure, let us consider what is going on throughout the vegetable world to-day. There are certain types of plant which, owing to special peculiarities, are adapted only to a special environment, while, again, there are others which, because of certain broad features that make for strength, endurance and rapid multiplication, are able to flourish in a great variety of surroundings.

The dock is a plant of the latter type. Its long fleshy tap root goes deep into the earth for food and moisture; it stores reserve material against seasons of scarcity, and it is, above all, possessed of such enormous powers of resistance to drought, that, if taken up and left on the surface of the ground till apparently quite desiccated, it will yet, when the rains have come, send branch roots into the earth, once more become established, and produce flower and fruit. The fruit, too, owing to its rough case, is easily transported on the coats of animals, and being light, and able to endure prolonged soaking, may float on water for considerable distances. The seed, too, possesses great vitality, and, even after being buried deep in the earth for some years, will freely germinate when brought into regions where oxygen is available.

The **daisy** family includes about ten per cent. of all known flowering plants and consequently must be well equipped to compete in the struggle for existence.

Among the special adaptations of the family are the simple but effective device for cross-pollination, which will be fully described in another place; the massing together of the flowers to form conspicuous heads; the protection of the inflorescence by means of an involucre, and the development of the tuft or pappus of hairs, that in so many species serves to distribute the seeds. The rosette form, too, is common in this family and constitutes one of the strongest weapons of the daisy, dandelion, catsear and many other members of the order.

Already we have seen how, owing to special adaptations of form, habit, and structure, certain plants are suited to a special environment. A number of factors determine the classes of plants that shall survive in any particular region, but by far the most important of these is the water factor. Exposure to wind, shade, temperature, the nature of the soil, the presence or absence of certain plant foods, are, as a rule, of minor importance. Since plants suited to a particular environment will oust all others that are not so well equipped as themselves to cope with the special conditions under which they are living, different plant societies have arisen, comprising certain typical groups, which in like situations show a remarkable similarity throughout the world. We have seen that scarcity of water is the chief factor that determines what kinds of plants shall form any particular group. At the one extreme we have **hydrophytes** (Gk. *hydor*, water, and *phyton*, a plant), plants which, like the water lily, live in the water; and at the other **xerophytes** (Gk. *xeros* dry), plants which, like the bracken fern, are suited to dry conditions and surroundings.

Mesophytes (Gk. *mesos*, middle) are plants adapted to an environment in which there is a good but not excessive supply of water.

Hydrophyte Societies.

Speaking generally, true **water plants** have the following adaptations suitable to their environment.

1. The epidermis is thin in all parts of the plant, for it is through this that the minerals and gases dissolved in the water are absorbed.

2. The roots, not being indispensable as special and exclusive organs of water and mineral absorption, are absent, or, when present, form as a rule mere hold-fasts serving to anchor the plants to the bottom. Root hairs are generally absent.

3. The vessels of the wood (*i.e.* the water conducting tissue), being no longer needed, since every part of the plant receives water direct, are much reduced or entirely wanting.

4. The fibres and other hard tissues that give strength and firmness are generally lacking, for the water itself affords all the support that is needed.

5. Large air spaces are developed in all parts of the organism, in the first place to float the plant, and in the next to conduct to the submerged tissues the air necessary for respiration.

6. The submerged leaves are usually long and strap-shaped as in the vallisneria, or narrow and arranged in whorls as in the water-starworts, or divided into numerous fine threads as in the water milfoils. In this way, damage by running water is obviated. They have chlorophyll in their epidermis, and are without stomata. Leaves which float on the surface, like those of the water-lily and pond-weed, are usually entire and oval or round, and have their stomata on the upper surface.

7. Water plants usually grow rapidly, branch freely, and reproduce enormously by vegetative means, usually by the decay of the older tissue setting the young shoots free, as in the pond-weeds and water-lily.

Among native hydrophytes the pond-weeds (*Potamogeton*) the water-milfoils (*Myriophyllum*), the water starworts (*Callitriche*), and the floating fern (*Azolla*) are the commonest. In the pond-weeds, the floating leaves are oval in shape while those below water are more ribbon-like, and thus less likely to sustain damage from running water. In the milfoils, the fine thread-like leaves are produced in whorls, those below being more slender than those above water. The small undivided leaves of the starwort are produced in great numbers, and cover large areas of ponds and sluggish streams. *Azolla* often forms large masses on the surfaces of pools, and in the spaces between its closely-packed leaves is the air by means of which the plant is enabled to float.

The chief introduced hydrophyte is the water-cress, which is plentiful in streams and ponds, and, like most other plants of this society, has its submerged leaves more divided than its exposed ones. It is one of those water plants that root in the soil, and are most plentiful round the edges of a stream or pond where the water is shallow. In other places the Canadian water weed (*Elodea*) is the predominant member of the society.

Ottelia ovalifolia, a water-plant from Australia, with large oval leaves, has now establishd itself in the ponds and lakes of the Auckland district. How it first got there is not known, but when once established it was probably spread by ducks, which carried the seed on their feet from lake to lake.

The author, while in Te Aroha, found that a South American water plant, *Hydrocleis nymphæoides*, had established itself in the backwaters of the Thames. Investigation showed that a settler had placed a number of water-plants, including the water-lily and water-hyacinth, as well as that already named, in a pond formed by an overflow from the Thames. In times of flood, some of these had escaped and established them-

selves as stated. Fortunately the current of the Thames is too strong for the water-hyacinth, or we might have our rivers and lakes choked with this pest, as has been the case in Florida and Queensland. So long, however, as this plant is in cultivation there is always the danger that through birds or other means it may get into favourable surroundings and become a source of serious trouble.

L. Cockayne, Ph.D., F.R.S., photo

Flax *(Phormium tenax)* swamp near New Brighton, Canterbury, being invaded by willows and European grasses.

Swamp plants, as well as water plants, are included among the hydrophytes. Their chief adaptation lies in the fact that their lower parts, which are buried in the mud, are suited to a life in water, while their aërial parts as a rule resemble those of ordinary land plants.

The commonest native swamp plants are the raupo (*Typha*) and the flax (*Phormium*), the latter requiring less water than the former. The spongy leaf of the raupo with its numerous air-spaces is characteristic of the true hydrophyte. The flax leaf, however, has a

xerophytic structure. It would appear that once the flax had its home on the dry heaths, where indeed it still flourishes in places; but that, being ousted from here by better-adapted competitors, such as the bracken fern and manuka, it took refuge in the swamp where some peculiar adaptability constitutional to the plant has enabled it to flourish ever since.

Clumps of cabbage trees appear in the drier swamp regions, while, rising from the wetter parts, may be seen the niggerhead (*Carex secta*), which builds out of its dead roots and stem a kind of trunk, that lifts it above the surrounding water. *Cotula coronopifolia,* a native plant of the daisy family, as well as pennyroyal and several introduced buttercups, are abundant round the edges of swamps.

Xerophyte Societies.

The dry wind-swept **heaths** are the true home of the xerophyte. Plants forming the heath societies, as we saw in dealing with the leaf, have, as adaptations to a dry habitat, a variety of devices for conserving water. In carmichaelia and the tanekaha, flattened branches perform the functions of leaves, and thus reduce transpiration, while, in the Wild Irishman, the work of leaves is done by rounded spines with the same result. *Olearia furfuracea*, a common heath plant of the daisy family, by means of a dense non-conducting layer of hairs on the under side of the leaf, and the tauhinu, by the rolling back of the two edges of the leaf-blade, have both solved the problem of water conservation. In the manuka, too, reduced leaf surface and thickened epidermis are drought-resisting characters. In New Zealand heaths the manuka is the predominant plant. Its extreme hardiness and ability to live under a great variety of conditions, even on the poorest soil, have enabled it to gain a footing almost everywhere, though it is to be noted that *Hakea acicularis*, an Australian hedge plant, has

ousted it from considerable areas in the Auckland district. However well manuka may be equipped to take its part in the Struggle for Existence, it is evident that, for this environment at any rate, the equipment of hakea is even better. Associated with the manuka, and also covering large areas, is the bracken fern, which, unlike many of its relatives, is a true xerophyte, as may at once be judged from the hard leathery nature of its leaf. Moreover, the facts that the upper epidermis of the leaf has no stomata, and that the mesophyll is protected by a second layer of colourless tissue situated below the epidermis, both point in the same direction. Two species of *Leucopogon* (white-beard), one a dwarf plant with stems only an inch or two high bearing hard, pointed leaves and producing yellow edible drupes, the other a dense shrub with somewhat larger leaves and bearing little branches of small white flowers, are common heath plants.

On the southern heaths, in addition to the plants already enumerated, huge hummocks of vegetation formed by the Wild Irishman are often among the most striking features. A considerable number, too, of drought-resisting plants are not uncommon; but it is on the northern heaths, especially on the gum-lands of the Auckland peninsula, that the greatest variety of species appears. There we find the erect and shrubby club moss (*Lycopodium densum*), *Olearia furfuracea*, a small tree of the daisy family, the dwarf cabbage tree, the mountain flax (*Phormium cookianum*) as well as the *Gaultherias*, *Dracophyllums*, and several of the small-leaved *Coprosmas*.

The **Sub-alpine Scrub**, despite the fact that it exists in regions where rainfall is abundant, nevertheless, owing to its exposed position, is of a highly xerophytic character. The two commonest forms of protection here are leaf reduction, as seen in so many of the whip-cord veronicas, and the dense felt of hair formed on the

undersides of the leaves, well shown in the great variety of olearias that flourish here.

The **Sand Dune** vegetation is again of a xerophytic character. The poor water-holding capacity of the sand itself and the constant winds that sweep over these areas render this a necessity. Sand plants, however, particularly the pioneers of the society show special adaptations. To fix the shifting

L. Cockayne, Ph.D., F.R.S., photo

Sub-alpine Scrub, Stewart Island, (*Olearia colensoi* on right, manuka on left)

sand they must either produce a dense mass of roots, or, as is more commonly the case, of underground stems that will bind the material of the dune together. The silvery sand-grass (*Spinifex hirsutus*) and the pingao (*Scirpus frondosus*) are two of the commonest sand-binders. The underground stems of the latter form an interlacing mass in the interior of the dune, while the stems of the former, produced originally on the surface, soon become buried with similar results. The low-growing habit of the sand plants, as seen in the

shore convolvulus (*Calystegia soldanella*) as well as those already mentioned, serves a double purpose. It checks loss of water by evaporation from the soil and reduces the surface exposed to the wind. At the same time it more or less checks the drifting of the sand. Over considerable sandy areas tree lupins have been planted and these, partly because in this soil, poor in nitrogen, they are able to derive their nitrogenous com-

L. Cockayne, Ph.D., F.R.S., phot

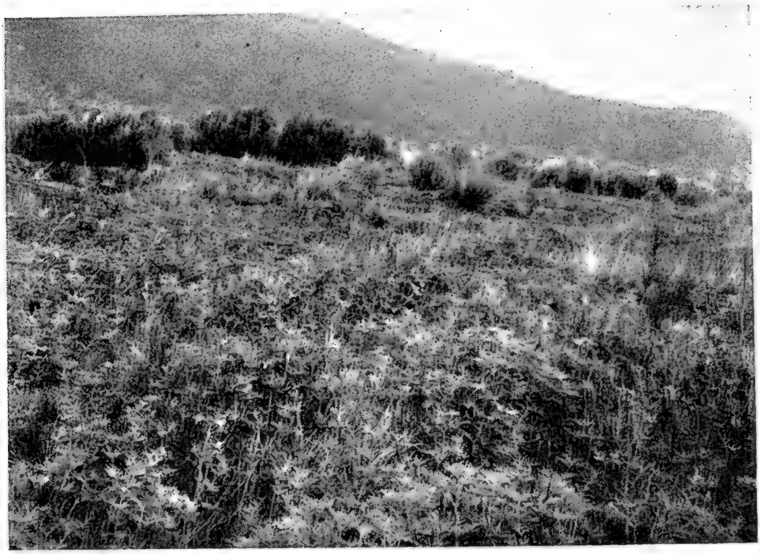
Sand-dune near mouth of the Rangitikei River, showing the sand-binder pingao (*Scirpus frondosus*).

pounds indirectly from the air, have established themseves and multiplied to form dense thickets that check the inroads of the sand.

Xerophytic Hydrophyte Societies.

Bogs differ from swamps in the fact that, in them, the nitrogenous compounds of the organic matter they contain do not decompose and become available for

plants, and that they are poor in lime, potash and phosphorus. The water of a bog, too, is strongly acid, and as a rule much colder than that of a swamp. The acid character is due doubtless to the absence of lime. Thus bog societies, though growing where water is plentiful, are of an entirely different character from those of the swamp. The plants of such societies are rather xerophytic in character. They have a diminished



L. Cockayne, Ph.D., F.R.S., photo

Bog, Stewart Island—chiefly umbrella fern.

power of root absorption and must therefore provide against excessive transpiration. Several reasons have been assigned for this peculiarity, none of which is entirely satisfactory. It is said, for instance, that the excessive coldness of bog water tends to check absorption, while it is also alleged that the presence of acids and certain mineral salts has a similar effect. In the true bog, bog-moss or sphagnum as a rule forms the basis of the plant society. This is by some said to be due to the fact that sphagnum, unlike most plants,

flourishes best in water poor in lime. Others, again, allege that sphagnum can grow only where there is but a slight amount of nutritive matter dissolved in the water. As time goes on, the mass of sphagnum dies below, but the young shoots continue to live above. As this goes on generation after generation, the mass is raised and spreads, often encroaching on and destroying surrounding vegetation. In some bogs, sundews and bladderworts abound. Both are able to exist where available nitrogen is scarce, for both trap insects and small animals whose proteins they digest. In the bladderwort, some of the leaves form small bladders with a kind of lid, which, by opening only inwards, serves as a trap for small aquatic animals, which enter and are there digested and absorbed. One of the umbrella ferns and a creeping lycopodium (club-moss) are also plentiful in certain bogs.

Salt-meadows are in much the same position as bogs, for here, too, though water is plentiful, there is present an excess of certain mineral salts, which would prove fatal to plants too freely absorbing them. The plants of the salt-meadows are therefore xerophytic in structure. Reduced absorption must be balanced by reduced transpiration. The most remarkable feature of these plant societies of the coast is the succulent water-storage tissue of which their members are composed. This we see in the ice-plant of the cliffs, as well as in the many salt-loving plants belonging to the beet family, *e.g.*, salicornia and suæda.

The mangrove, which is found plentifully in the wide estuaries of the Auckland peninsula, is one of the most remarkable of the sea-coast plants. The peculiarities of the germination of its seed, and the establishment of its seedling, as well as its development of aërial breathing-roots, have already received attention. The mangrove is a plant which has, with

wonderful thoroughness, become adapted to its surroundings.

Mesophyte Societies.

Mesophyte societies form, as a rule, either grass-land or forest. Where the rainfall is abundant we find the forest, particularly where the exposure is not too great or the cold too intense. Where the rainfall

L. Cockayne, Ph.D., F.R.S., photo

Tussock grass-land of Malvern Hills, Canterbury, showing Wild Irishman *(Discaria toumatou)* in foreground. The grass is a fescue *(Festuca novae-zealandiae)*.

is less in quantity, more especially where showers occur at frequent intervals, we have grass land.

The **grass-lands** occur chiefly in three regions, the Taupo steppe lying to the South and East of Ruapehu, the Canterbury Plains, and a large part of Central Otago. The absence of forest to the east of Ruapehu, though due doubtless in a measure to scanty rainfall, may to some extent also be accounted for by the extremely porous nature of the soil and the effect of recent volcanic action. That the two latter alone

would not be sufficient to prohibit forest growth is abundantly shown by the luxuriant vegetation on Ruapehu's western slopes, which forms a striking contrast with the Onetapu desert on its eastern side, where reduced rainfall, together with unfavourable soil conditions, has resulted in an almost total absence of plant life. Central Otago and the Canterbury Plains no doubt owe their steppe character to the same cause. On the Canterbury Plains, too, as well as in Central Otago, the rainfall is, generally speaking, insufficient to permit of forest growth. Before reaching Canterbury, the available moisture in the north-west winds is precipitated on the western slopes of the Southern Alps, so that these winds, after crossing the Alps, instead of bringing a supply of moisture, actually parch the soil and vegetation over which they blow. Add to this the fact that on the east there is no mountain range or other permanent cause for precipitation of the moisture brought by the prevailing north-east winds, and we account at once for the striking contrast between the almost tropical luxuriance of the Westland forests and the essentially steppe character of much of the Canterbury Plains. On the Taupo plateau, as well as in Canterbury and Otago, the soil is not clothed with a close sward, as is the case in European grass land, but is covered with scattered bunches or tufts of grass belonging chiefly to native species of poa and fescue. Among these are the smaller tufts of danthonia, the native oat-grass. The tufted nature of these grasses gives to the steppes the name of tussock-land.

In many parts of New Zealand, pastures of the European type have been formed by the industry of man. Here we find perennial rye, cocksfoot, sheep's fescue, and several clovers, as well as a great variety of noxious weeds whose seeds have been accidentally introduced from abroad.

New Zealand **Lowland Forests** are as a rule of an essentially tropical nature. True **rain-forests,** they reach their greatest perfection at the foot of the western slopes of the Southern Alps, where the rainfall is greatest.

Generally speaking, these are **mixed forests,** and consist of several strata of vegetation, composed of a great variety of species. The topmost layer consists of lofty trees, the next of the lower trees and tallest

L. Cockayne, Ph.D., F.R.S., photo

Rain Forest (kauri), North Auckland.

shrubs, the third of the undergrowth of tree ferns and low shrubs, and the last of the mosses, filmy ferns, and other shade-loving vegetation that clothe the forest floor. The abundance of epiphytes comprising orchids and astelias, as well as several ferns, shrubs, and small trees, and the profusion of lianes like the kiekie, supplejack, rata, and parsonsia, all go to emphasize the truly tropical character of the New Zealand rain-forest. In the northern part of New Zealand, sometimes one and sometimes another is the dominant species. Now it is the tawa, now the kohekohe, now

L. Cockayne, Ph.D., F.R.S., photo

Rain Forest, Stewart Island.

the rimu, with here and there a sprinkling of karaka, rewarewa, mangeao, and pukatea.

In certain parts of the Auckland Peninsula the mixed forest disappears and the **kauri** becomes the dominant tree. These trees, as a rule, appear in groups, and the spaces between these groups are occupied with a varied mass of trees, shrubs, and ferns. The taraire,

L. Cockayne, Ph.D., F.R.S., photo

Exterior view of southern-beech forest of dry district, near mouth of Broken River, at about 2,500 feet altitude.

the silvery tree-fern, and the North Island rata are among the commonest forms, while kidney ferns and astelias that are not epiphytes clothe the ground.

The **kahikatea** sometimes occupies low swampy plains to the exclusion of nearly all other forest trees. Here, in the undergrowth may be seen lawyer and certain species of coprosma, while high up the stems of the pine scrambles the kiekie, rooting as it goes. On leaving sea level, new factors other than the abundance or scarcity of water, begin to make themselves

appreciably felt. As we ascend the mountain sides the slopes become more exposed to wind and the extremes of temperature are greater, so that the mixed forest of necessity gives place to the hardy **beech**, which now becomes the dominant tree. Ascending still further we reach the sub-alpine scrub, beyond which is the alpine meadow, succeeded finally by the desert region at the summit.

L. Cockayne, Ph.D., F.R.S., photo

Interior of southern-beech forest of wet district, Arthur's Pass, at about 2,800 feet altitude.

A walk from Ohakune to the summit of Ruapehu will show all these grades of vegetation. At Ohakune, at an elevation of about 2000 ft., the forest is mixed in character, tall and luxuriant, and, as in most other lowland districts throughout New Zealand, typical rain-forest. The rimu and matai are the dominant trees, but the tawa, mahoe, wineberry, panax, horopito, and fuchsia are also present. The ascent from Ohakune is at first very gradual, and just as gradual is the

change in the character of the vegetation. By degrees, the tall rimu become rarer and finally disappear altogether, yielding place at about 3,000 ft. to the large tooth-leaved beech which now becomes the dominant tree. Parasitic on this is the scarlet-flowered mistletoe. Since the crowns of the beech trees form a leafy roof almost impenetrable to light the forest becomes more open, the scanty undergrowth being confined chiefly to species of coprosma and the magnificent fern known as the Prince of Wales Feather. After advancing a few more miles and ascending another thousand feet or so, the vegetation shows a perceptible change. The beech trees are no longer tall, and are now, moreover, associated with considerable numbers of the curious mountain cedars: the ground, too, is covered with dense, soft mats of various kinds of moss, while here and there the stinking coprosma appears. Soon the tooth-leaved beech disappears and the more stunted mountain beech becomes the dominant tree. Finally, about nine miles from Ohakune, at an elevation of about 4,000 ft., we reach the limit of the forest vegetation. At this point the trees are seldom over ten feet high, and, especially on the ridges, are remarkable for their weather-worn wind-swept appearance. At the same time, streamers of grey lichen, that hang from their trunks and branches, give a truly weird aspect to these stunted mountain beeches. Here, too, at the extreme upper limit of the forest, are found the mountain toa-toa and mountain rimu, both forms well-suited to withstand the blasts that sweep their lofty home. These, together with shrubby veronicas and composites, mingled with low-growing forms of the gnarled and stunted mountain beeches, comprise the almost impenetrable thicket known as the sub-alpine scrub.

Tree vegetation now gives way to the **Alpine meadow,** which comprises such plants as tussocky

native grasses, the beautiful daisy-like celmisias, and small veronicas, with here and there dwarf mountain totaras and several varieties of heath. It is on the coastal ranges of Nelson, however, that the alpine carpet spreads its greatest profusion of species. Here, as in other alpine and arctic meadows, the flowers are of extreme beauty, and often large in proportion to the size of the plant that bears them. But there is this

L. Cockayne, Ph.D., F.R.S., photo

Alpine meadow showing tussock and celmisias, with stunted beech in the distance.

peculiarity, whereas in other countries the flowers, such as for example the gentian, are remarkable for the intensity of their colours, those of the New Zealand alpine meadow are in most cases either white or yellow. The white celmisias and buttercups are, however, the true aristocrats of the native flora. Yet plants growing in such situations have to contend with a most adverse environment. They are subjected to great extremes of heat and cold and exposed to fierce

storms. When mist and rain are absent and the sun shines through the rarefied atmosphere, the heat is often intense and transpiration therefore extremely active. At night again this rarefied condition of the air permits of rapid radiation to the clear sky, and, even in summer, frosts are of frequent occurrence. As adaptations to these harsh conditions, numerous peculiarities of habit and structure have appeared in plants that form these alpine meadows. To guard against injury by storm, and, at the same time, by imprisoning the air to reduce extremes of heat and cold, the cushion and rosette habits, the former well seen in the mountain rimu and New Zealand donatia, and the latter in the great variety of celmisias, have been assumed. To check transpiration, which, owing to constant wind and intense heat, would at times, be excessive, special adaptations of leaf surface, structure and position have arisen. In the spear-grasses the leaf is hard and leathery with an extremely thick cuticle, and at the same time is placed in an almost vertical position, so that it is only in the early morning and late evening that it can receive on its blades the direct rays of the sun. The most frequent adaptation, however, is the dense mat of hairs that covers the under-sides of the leaves, as seen in the celmisias and many other plants of this family. These hairs, as we have already noted, not only check the escape of transpired vapour, but, at the same time, by forming a non-conducting layer, modify extremes of heat and cold.

Successions.

It often happens that, in a particular locality, one plant society succeeds another. Indeed, if we consider for a moment we shall see that the vegetation of the earth as it stands to-day must be the product of a long series of such successions. Much can be learned

from watching the new vegetation that springs up in a region devastated by a bush fire. First cat's-ear, certain grasses, thistles and other annual weeds appear. These, as a rule, are followed by quick-growing shrubs and small trees such as the manuka, wineberry and rangiora. But, as time goes on, true forest trees begin to make their appearance, small at first, but gradually raising themselves above, and dominating the surrounding vegetation. In the raupo swamp may be observed a process more gradual and natural, for here there is no need for the aid of fire. As the raupo dies down year after year, the shallower parts of the swamp finally become more or less solid, so that rushes, sedges, and plants of that nature are able to gain a footing. These pave the way for buttercups, penny-royal, and coarse grasses, till the whole swamp may be gradually converted into a wet meadow.

On many of the lava streams of New Zealand it is possible to observe the first beginnings of vegetation, as well as the different stages of the various successions that appear. Rangitoto, a volcanic cone rising from the sea in the neighbourhood of Auckland, is admirably suited for such investigation. It would appear from the extent of volcanic action, that the original flora must, in the various eruptions, like that of Krakatoa, have been utterly destroyed. Here the first signs of vegetation visible to the eye are the grey lichens that cover the bare rock. These by their decomposition form a humus which gives a footing to the mosses. The latter form mats that catch the dust consisting of powder formed from the decomposed rock and tiny particles of organic material broken from neighbouring lichens and mosses. When these collecting grounds have a sufficient supply of humus and decomposed rock, a drought resisting fern, the creeping polypody, makes its appearance, and, forming a deeper and more open mat, collects the wind-drift more

rapidly than the moss. These polypody mats often contain a considerable amount of soil so that now there is a chance for the creeping mühlenbeckia, which, with its masses of slender wire-like shoots, forms a hummock that is the most efficient collector of wind-drift the lava-stream possesses.

Now may appear terrestrial astelias, the koromiko and the myrsine, to be followed by the pohutukawa, the broad-leaf, the akeake, and, in many places, the manuka. The establishment of a flora under such conditions is truly one of the triumphs of Nature. How many millions of seeds must have been blown from the mainland, have fallen on the island and germinated before a single seedling was able to establish itself? We can imagine the fortunate combination of circumstances that contributed to the result—an early autumn, a moist, mild winter, followed by a cool, wet summer. Then, perhaps, one among many thousand seedlings would get its roots favourably placed to secure the highest possible amount of the scanty moisture the dust in some crevice and the porous lava beneath were able to supply.

Summary.

A Struggle for Existence goes on among plants, in which those best adapted to the particular environment survive, and those not so well adapted go to the wall. Some plants are suited to a great variety of environments; others only to special environments. The latter form plant societies. **Water supply** is the chief factor in determining the plants that shall constitute any society.

Hydrophytes. Water plants have thin epidermis, reduction of roots, wood-vessels and supporting tissues. The submerged leaves are much divided, the floating ones rounded and entire with stomata on upper surface. They grow rapidly and reproduce

vegetatively. Swamp plants are like hydrophytes in their lower submerged parts, but like land plants in their upper aërial parts.

Xerophytes are drought-resisters, and occupy chiefly the wind-swept heaths and the sand-dunes. Reduced leaf-surface and other adaptations for checking transpiration are seen here.

Xerophytic Hydrophytes live in water or wet situations, but, owing to excess of certain materials in the water, have to guard against too great water absorption and have thus assumed a xerophytic character. Such plants are found in sphagnum bogs and salt meadows.

Mesophytes require a moderate rainfall, and such societies form either forest or grass land, the latter requiring a less but more evenly distributed rainfall than the former. New Zealand lowland forests are rain-forests, and may be mixed forest, kauri forest, or kahikatea forest. Ascending the mountains we pass through the beech forest, sub-alpine scrub, alpine meadow, and finally arrive at the climatic desert at the summit.

QUESTIONS ON CHAPTER VII.

1. What is meant by the "Struggle for Existence," the "Survival of the Fittest," "Natural Selection"?
2. What weeds have you found the most persistent? Give reasons for this persistence.
3. What is a weed? Why do garden vegetables need help in their struggle for light and food?
4. Why is the manuka able to establish itself in almost any situation?
5. How is it that plant societies come to be formed?
6. What is the chief factor determining the nature of the plants forming any particular plant society? What other factors may operate?
7. What conditions give rise to grass-land and what to forest?

8. Show how the plants forming an alpine meadow are adapted to their surroundings.
9. Compare the rain forest with the beech forest.
10. Describe the ways in which water-plants are adapted to their surroundings.
11. Compare the kauri with the kahikatea forest.
12. Describe the vegetation of any swamp you know.
13. Examine the plants growing under a quick hedge. Describe their characteristics, especially noting how they differ from plants of the same species growing in the open.
14. Describe the vegetation of the forest-floor.
15. Name six common weeds and show in what way they are specially equipped to succeed in the struggle for existence.
16. The island of Singapore produces over 2000 native species of flowering plants; the Isle of Wight (about equal in area) 800; an equal area of the Egyptian desert under 200. Account for these differences.
17. Give a full account of the establishment of a flora on the sides of a railway cutting.
18. Describe sand-dune vegetation in any region with which you are acquainted.
19. What plants grow along the margins of lakes, ponds, and rivers? Distinguish those which grow with their stems (*a*) wholly in the air, (*b*) partly in the air, (*c*) wholly submerged. Show by sketches what you mean by the zones of vegetation along the water margin.
20. Write a list of any plants you have found growing with their leaves submerged in water. How do such plants obtain the gases they require for respiration and photosynthesis?
21. What plants establish themselves most readily on stiff clay soils where there is very little humus?
22. What plants are most abundant where the soil is composed largely of decaying vegetation?
23. What kinds of plants are usually found growing in regions much exposed to violent winds?
24. What peculiarities may be noted in plants that usually have erect stems when such plants are growing in a district constantly swept by violent winds that almost invariably blow from the same quarter?

Chapter VIII.

PLANT DESCRIPTION.

In connection with plant description it will be well once more to assert the importance of field work, for it is by this alone that the student can arrive at an understanding of the plant as a living whole, and appreciate its relation to its environment. The examination of the root, stem, leaves, and general appearance of the inflorescence as well as of the individual flowers of which it consists should always where possible take place before the plant is removed from the soil. In the case of wild plants, it is, of course, an advantage to study them in their proper habitats, growing under natural conditions. The next best thing is to have them growing in the school garden and carry out the investigation there. In the rare instances where even this is impossible the students should procure enough fresh specimens of the whole plant to supply each member of the class with material for examination in the laboratory or class-room.

To make any systematic classification of plants demands an investigation of the whole structure and development of each plant organ with microscope as well as naked eye. Even now, botanists are undecided as to the class in which certain plants should be placed, while, with respect to others, the fact that they seem to have no near relatives now in existence makes it difficult to assign them a place at all. There are, however, among most well-known plants certain points of likeness and difference that render it possible to arrange them in groups. In making such an arrangement it will be noted that the reproductive are much more constant than the vegetative organs. Throughout

large groups of plants, whose leaves and stems may differ enormously, the flowers are practically the same. The kowhai flower is the same type as that of the pea, but one plant is a shrubby tree while the other is a herb. Compare again the hard leathery leaves of many olearias with the soft spoon-shaped ones of the field daisy. Yet the flower is practically the same in both. The explanation is simple. It is through its vegetative organs that a plant comes into relation with its environment, and, therefore, in these, to meet changes in its surroundings, modifications have arisen. The reproductive organs are concerned always with the same thing—the production of the seed, and as, speaking generally, the same method will serve this purpose in almost any environment, these organs have undergone but little change.

It would seem from their close resemblance that there are certain plants which at no very remote period had a common ancestor. These belong to the same **species**. There are certain groups of species which from their general resemblance to each other, would appear at a period somewhat more remote, to have also been derived from the same ancestor. These groups of species form a genus. **Genera** may again be grouped into **natural orders**, and, from the fact that the different genera forming any one order show in their broader features a close resemblance to one another, it seems clear that these, too, at a period still more remote, had a common origin. Natural orders or families may again be arranged in tribes. Continuing further, the groups become progressively larger till finally we have the following classification:—

1. **Cryptogams** produce no seeds, *e.g.*, ferns.
2. **Phanerogams** produce seeds.
   (*a*) **Gymnosperms** have naked ovules, *i.e.*, not enclosed in an ovary, *e.g.*, the pine.

(*b*) **Angiosperms** have their ovules enclosed in an ovary.

i. **Dicotyledons** have two seed leaves, *e.g.*, pea.

ii: **Monocotyledons** have one seed leaf *e.g.*, lily, grasses.

Naming plants.—Each plant is by botanists given two names; the first indicates the genus, the second the species, *e.g.*, *Myrtus bullata.*

(*a*) **Myrtus** denotes that the plant belongs to the *myrtus* genus. This is the generic name.

(*b*) **Bullata** is the specific name which distinguishes this particular species of the myrtle genus. Bullata denotes "embossed," the name being given on account of the embossing of the leaf.

Description.—In describing plants the student should make sure that he has omitted none of the cardinal points. It is, of course, always well where possible to describe such minor details as the nature of a leaf surface or the colour of a petal, but it would be unpardonable to mention only such matters and omit all notice of the number and arrangement of members in different whorls of a flower; for it is on these latter that classification is largely based. It is important, above all things, to state in every case the **number** of sepals, petals, stamens and carpels, to indicate their **cohesion** (*i.e.*, to say whether they are united or free), and lastly to state precisely the **adhesion** of each whorl; is the flower hypogynous (below the ovary), perigynous (lifted up on the receptacle tube round the ovary), or epigynous (set on top of the ovary)? These are merely the essentials, the omission of any one of which would constitute a fatal defect in the description of a plant: there must, of course, be noted many other points, for instance those connected with habit, root, stem and leaves, as well

as those that concern the reproductive organs. These, however, will be illustrated in dealing with the prescribed natural orders. Objection has, with some degree of justice, been raised to the tabular method of description, as leading to a stereotyped form of answer, and precluding reference to exceptional matters not comprised within it. It would seem that by keeping to this form, and yet, at the same time, allowing the greatest freedom in the description of matters for which it does not specially provide, this difficulty is obviated. For its convenience of arrangement and the assistance it affords in ensuring the inclusion of essentials, the tabular form will be employed in the following descriptions. Accurate drawings showing the general appearance of the plant and its organs, as well as the junctions and details of the several parts, are of prime importance. A clear sketch will often be more illuminating than a whole page of description. A vertical section as well as the so-called floral diagram (*i.e.* a ground plan of the flower) should always be given.

DICOTYLEDONS.

Dicotyledons have net-veined leaves, stems showing a ring of vascular bundles with cambium, two cotyledons to the seed, and, as a rule, the parts of the flower in fours or fives.

Ranunculaceæ.

The Hairy Buttercup (Figs. 123-124) (*Ranunculus hirsutus*) is a typical plant of this order, and may be described as follows:—

Habit.—A hairy perennial plant, with erect flowering stem and straight rootstock (*i.e.*, a short rhizome). It flourishes in damp places and in New Zealand flowers nearly all the year round.

Root.—Fibrous.

Stem.—A rootstock throwing up an herbaceous (*i.e.* not woody) erect, round, hollow, hairy, green aërial shoot.

Leaves.—Both radical (*i.e.*, produced from the root-stock) and cauline (*i.e.*, produced on the stem); cauline leaves alternate, simple; lower leaves deeply divided; upper narrow and not divided; a well developed sheath is present especially in the radical leaves; blades reticulate veined (*i.e.*, net veined), hairy, exstipulate (no stipules).

Inflorescence.—A scorpioid cyme, *i.e.*, the first flower is terminal, the next flower being produced on the stalk behind this and then raised above it, this going on alternately first one side and then the other.

Flower.—Hypogynous (*i.e.*, below the ovary). Complete (*i.e.*, has all parts, viz. sepals, petals, stamens, carpels); actinomorphic (*i.e.*, is regular, and can be divided into two similar halves in any direction in the vertical plane); about three-quarters of an inch in diameter, yellow.

Calyx.—Five sepals, aposepalous (*i.e.*, sepals not united), inferior (*i.e.*, fixed to the receptacle below the ovary) hairy, green.

Corolla. Petals five, apopetalous, hypogynous (*i.e.*, fixed to the receptacle below the ovary); surface showing a beautiful sheen; each petal with a nectary or honey gland appearing at its base as a small swelling.

Andrœcium (*i.e.*, the male organ or stamens of the flower), stamens indefinite (*i.e.*, very numerous), hypogynous, free (*i.e.*, not united with one another); filament (*i.e.*, stalk of stamen) long; anther (*i.e.*, little knob at top of stamen) two lobed; ~~in~~extrorse dehiscence (*i.e.*, the groove of the anther opens towards the centre outside of the flower); basifixed (*i.e.*, the filament is fixed to the base of the anther).

Gynœcium (*i.e.*, the female organ of the flower consisting of the carpels), carpels indefinite; apocarpous (*i.e.*, the carpels are not joined together but are scattered over the surface of the receptacle); spirally

arranged on a dome-shaped receptacle, ovary superior (*i.e.*, fixed to the receptacle above the other parts of the flower); stigma terminal, one ovule in each ovary; basal placentation (ovule joined to base of ovary).

Fruit a collection or etario of achenes (*i.e.*, one-seeded, dry, indehiscent fruits); seeds possess a little endosperm.

Pollination. The outer stamens ripen first and then the inner ones. The carpels ripen between the two sets of stamens. In this way either self-pollination or cross-pollination can take place. The flowers are visited by numerous insects for honey and pollen, and these creeping over the flowers may either bring pollen from another flower and so cross-pollinate, or they may distribute pollen from the stamens to the pistil of the same flower and produce self-pollination.

Characteristics of the order—flower hypogynous with numerous free stamens and carpels, and fruit an etario either of achenes or follicles.

The flowers of the Ranunculaceæ are primitive in several respects: *e.g.*, the spiral arrangement of the carpels, the numerous stamens, the free carpels and elongated receptacle which is nearer to the true branch form than in most flowers.

The order is rich in poisons such as aconite and hellebore.

Floral Formula:—K5, C5, A∞, G $\underline{1 \text{ to } \infty}$.

(*a*) K5 means there are five sepals not united. If they were united it would be written thus: K(5).

(*b*) C5 means that there are five petals not united.

(*c*) A∞ means that there are numerous stamens.

(*d*) G $\underline{1 \text{ to } \infty}$ means that the carpels may in different genera of the order be one, two, three, and so on to almost any number.

RANUNCULACEAE

FIG. 123 BUTTERCUP

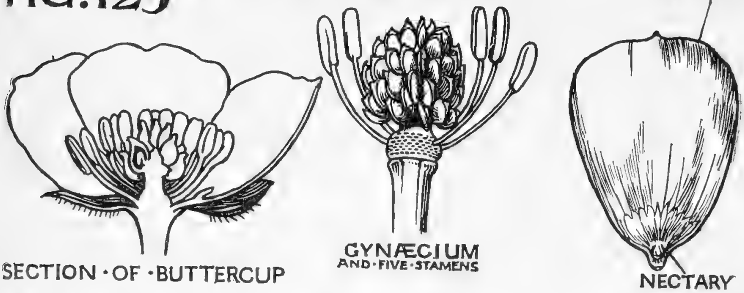


FIG. 124

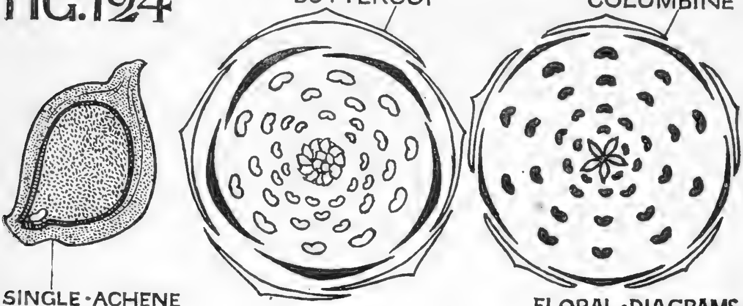
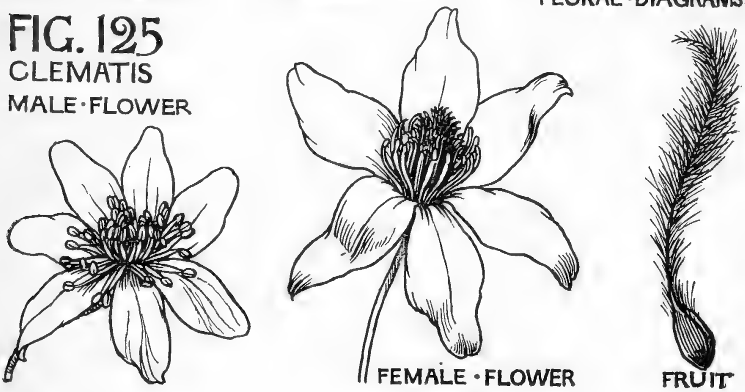


FIG. 125
CLEMATIS
MALE · FLOWER



The line drawn below indicates that the pistil is superior, *i..e.*, set on the receptacle above the rest of the flower. A line above would indicate that it was inferior.

NEW ZEALAND REPRESENTATIVES.

1. **Ranunculus lyalli,** the so-called Mount Cook Lily is a large white buttercup growing on the summits of the Southern Alps—perhaps the finest buttercup in existence. New Zealand is rich in mountain buttercups.

2. **Clematis indivisa** (Fig. 125)—a woody climber found chiefly on the edge of the forest. The leaves are compound (three lobed) and leathery, and the plant climbs by twisting the leaf petioles round objects with which it comes into contact. The plant is dioecious (*i.e.*, the staminate flowers or flowers bearing stamens, and the pistillate flowers or flowers bearing pistils, are produced on different plants). The flower is large and white, the sepals being petaloid and the petals absent. The male flower is the finer. In the staminate flower we have stamens but no carpels, while in the pistilate flower there are numerous carpels surrounded by a ring of staminodes (*i.e.*, stamens that have no anthers and thus produce no pollen).

The presence of these staminodes would seem to show that the clematis was not always dioecious. The **fruit** is an achene as in most other members of this order, but the style becomes feathery and forms a convenient means for distribution of the seed by the wind.

The clematis belongs to this order, because, like the buttercup, it has a hypogynous flower in which there are numerous free stamens and carpels.

COMMON EXAMPLES.

In the following common plants the chief characteristics are the same as those of the buttercup and clematis, but there are certain points of difference,

which, though markedly distinguishing them from examples already described, are not sufficient to warrant their being placed in separate orders.

Peony—tuberous roots and large flowers; sepals five, passing gradually outwards into the foliage leaves; five or more petals without nectaries; numerous stamens and two or three large fleshy carpels, joined at their bases and producing nectar from a disc by which they are surrounded.

2. **Columbine** (*Aquilegia*) five petaloid sepals; five petals with long nectar spurs; numerous stamens in regular rings; inner stamens without anthers; carpels five or more; fruit an etario of follicles.

3. **Nigella** (*Love-in-a-mist, Devil-in-the-bush*). Flower has involucre of five leaves; five petaloid sepals; five to eight pocket-like nectaries each with a lid; five carpels with united ovaries which split when ripe along the partitions.

4. **Larkspur** (*Delphinium*). Five petaloid sepals, the uppermost spurred; only two upper petals developed as a rule; the two spurs of these project into the sepal spur and are pressed together so as to form a tube above and a solid nectary below; carpels three to five often reduced to one; fruit an etario of follicles or a single follicle.

5. **Anemone.** Sepals petaloid, petals wanting. In double flowers many of the stamens become petaloid. Receptacle much elongated.

Cruciferæ.

The **Wallflower** (Fig. 126-127) (*Cheiranthus cheiri*) is a typical crucifer.

Habit. A perennial plant largely cultivated for its flowers.

Root. Much branched woody tap-root (as in the case of most dicotyledons).

Stem. Woody below and herbaceous above; erect, branched, ribbed; lower part covered with pale brown bark; upper portion coloured green, hairy.

Leaves. Cauline, alternate (in five rows), sessile, lanceolate, acute, entire and reticulate-veined. Upper side dark green and slightly hairy; lower side pale green and more hairy; exstipulate.

Inflorescence. Indefinite, raceme.

Flowers. Complete, actinomorphic, cruciform, hypogynous.

Calyx. Sepals four, in two whorls; aposepalous, inferior; lanceolate, hairy; two inner pouched at the base. (Notice glistening drop of nectar in pouch).

Corolla. Petals four, apopetalous, hypogynous, clawed; usually reddish-brown in colour, scented.

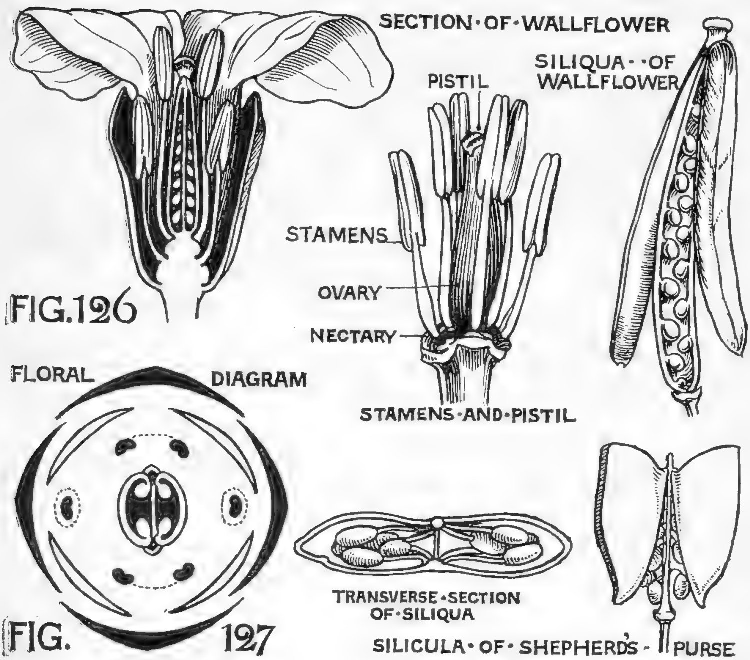
Andrœcium. Stamens six, hypogynous, free, in two whorls, tetradynamous (*i.e.*, in two sets—a single pair of opposite stamens, and two pairs opposite each other at right angles to these). The two short lateral stamens form the outer whorl; the four inner stamens are in two opposite pairs, anterior and posterior, each pair having arisen from the splitting of a single stamen. The nectaries are small green glands situated on the receptacle at the bases of the short stamens; the nectar gathers in the pouches of the lateral sepals—filaments thick, anthers two lobed.

Gynœcium.—Carpels two, syncarpous; style short; stigma two lobed; ovary superior, linear, spuriously two-celled, the septum or dividing wall being formed by ingrowths from the placentæ; ovules numerous on two parietal placentæ.

Fruit.—A siliqua (*i.e.*, a two-celled fruit formed from a superior ovary derived from two united carpels, and spuriously two celled by ingrowths from the the placentæ). It dehisces by the carpels breaking away from the septum and leaving the ovules attached thereto.

Pollination.—Self-pollination often occurs, since, in most cases, stamens and carpels ripen at the same time. Small flowers with spreading petals are visited by short- tongued insects (flies, etc.), and some of them (*e.g.*, Shepherd's purse, whose flowers often have only

CRUCIFERAE



two to four stamens) are regularly self-pollinated. The larger flowers, in which the sepals are erect and hold the clawed petals together so as to form a sort of flower tube, are visited by bees and butterflies, the nectar being partly concealed and protected from the rain. The large light-coloured evening-

scented flowers such as we find in several stocks are pollinated by night-flying moths.

Characteristics of the order.—Perianth free; flower hypogynous; parts in twos and four; corolla cruciform; stamens six; tetradynamous; fruit a siliqua or silicula. The leaves usually have a turnipy smell, and the plants have medicinal qualities. They are largely used for food and contain organic compounds that prevent scurvy. The flowers of the cruciferæ show a considerable advance on those of the ranunculaceæ in the reduction of the stamens, their multiplication and peculiar arrangement in two whorls, and in the reduction and union of the carpels.

Floral formula—K $2 + 2$ C 4. A $2 + 2 \times 2$ G $(\underline{2})$.

K $2 + 2$ means that there are 4 sepals arranged in two whorls.

C 4 that there are 4 free petals.

A $2 + 2 \times 2$ that there are 6 stamens in two whorls, 2 in the first and 4 in the second, each stamen in the latter whorl being formed by division of a single stamen.

G $(\underline{2})$ that there are two united carpels forming a superior ovary.

New Zealand Representatives.

1. **Cardamine hirsuta** is a small crucifer common throughout New Zealand. It seems to grow best by the sides of shaded paths and streams near the edge of the bush. The leaves are in appearance not unlike those of a delicate young watercress plant, and have the turnipy smell and flavour characteristic of this order. The flower is very small but has the characteristic cross form; stamens sometimes only four. Fruit very narrow. This is perhaps the crucifer most readily available.

2. **Notothlaspi rosulatum**, a crucifer of the Southern shingle slips, forms, with its leaves, an umbrella-shaped

rosette the edges of which touch the ground, thus enclosing a space under a dome-like roof, which throws off the rain to soak through the shingle to the long tap-root. The air enclosed within the space protects the plant against the extremes of heat and cold that prevail on the mountains that form its home; for air, being a bad conductor of heat, keeps the under sides of the leaves cool during the heat of the day, and warm through the intense cold of the night. The flowers have short stems and are densely crowded together.

Common Crucifers.

1. **Stocks** are grown for their flowers. The night-scented stock is pollinated by night-flying moths.
2. **Watercress** is common in ponds and streams.
3. **Cabbage** are cultivated for their leaves, **cauliflower** and **broccoli** for their inflorescence buds, **Brussels sprouts** for the axillary leaf buds, **turnips** and **radishes** for their roots, **mustard** for its seedlings.
4. **Shepherd's Purse** is a common weed in which the fruit is a silicula or short siliqua (Fig. 127).
5. **Honesty** is a garden plant grown for its silvery oval siliculæ.
6. **Candytuft** is another common garden flower.

Leguminosæ.

There are three main branches of the Leguminosæ, two of which, the **Mimosaceæ** (introduced) to which the wattles belong, and the **Papilionaceæ** (both native and introduced) (L. *papilio*, a butterfly) which comprises all the bean-like plants, are common throughout New Zealand; the Garden Pea (*Pisum sativum* Figs. 128-129) is a characteristic plant of the sub-order Papilionaceæ.

Habit. A weak annual plant which climbs by means of tendrils.

Root. A branched tap-root with many nodules on it. These indicate the presence of bacteria that absorb free nitrogen from the air.

Stem. Herbaceous, ribbed, glabrous (without hair), green.

Leaves. Cauline, alternate, pinnately compound, stipulate (stipules large, green, and persistent). The leaf ends in a branched tendril which really consists of the midrib of the terminal leaflet, the blade having disappeared.

Inflorescence. Axillary, in two or three flowered racemes.

Flower complete, zygomorphic (*i.e.*, irregular) papilionaceous, diameter about an inch, perigynous.

Calyx. Sepals five, synsepalous, green, hairy, inferior.

Corolla. Petals five, apopetalous, slightly perigynous (*i.e.*, lifted up on the receptacle), consists of standard on outside (posterior), two wings (lateral), keel of two united petals (anterior).

Andrœcium. Stamens ten, in two whorls, perigynous diadelphous (*i.e.*, in two groups; nine of the stamens are united by their filaments to form a tube, the posterior stamen being free). In the kowhai, the stamens are all free and the flower is of a highly perigynous nature. At the base of the stamens nectaries occur. The nectar formed by them accumulates between the stamens at the base of the ovary.

Gynœcium. Monocarpous (*i.e.*, only one carpel); superior; sutural placentation (*i.e.*, ovules on suture); style bent at right angles, usually short; stigma, terminal.

Fruit. A legume, seed without endosperm.

Pollination. Flowers, irregular and brightly coloured, attract insects. The pea is generally pollinated by the bee. An insect alighting on the flower is partly supported by the wings of the corolla.

LEGUMINOSAE

FIG.128

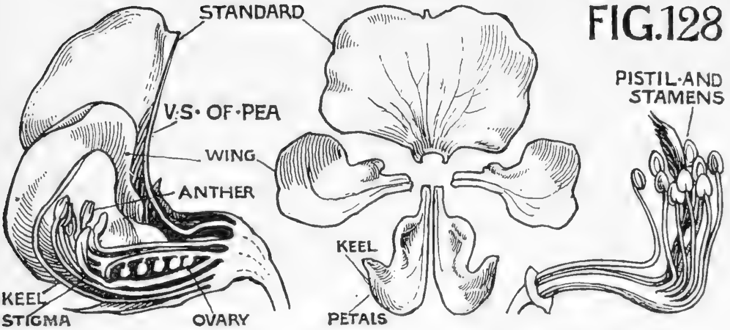


FIG. 129
PEA FLOWER

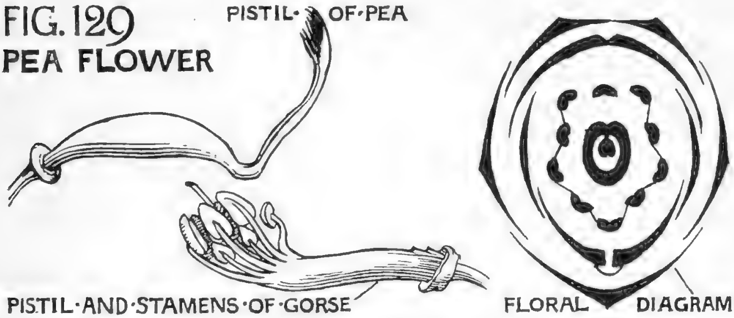
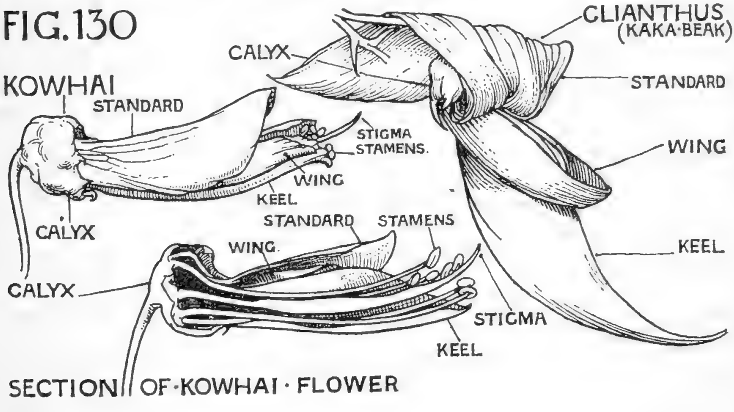


FIG.130



These are depressed and carry down with them the keel to which they are hinged. The stigma and stamens are enclosed in the keel, but by its depression are exposed. The stigma first strikes the under side of the insect's body, and in so doing receives any pollen it may have brought from another flower. Next the stamens strike the underside of the insect and dust it with pollen. The keel on which the insect now rests has been depressed below both stamens and stigma so that the insect flies away without again touching either, and thus self pollination is obviated. When the insect goes to another flower the stigma strikes and receives the pollen from the first, resulting in cross-pollination.

Characteristics of the Papilionaceæ. Flowers apopetalous, perigynous (*i.e.*, the petals and stamens are lifted up on a cup formed by the calyx tube, there being a space between the tube and the ovary of the flower); papilionaceous (*i.e.*, butterfly shaped); stamens ten, usually monodelphous or diadelphous (*i.e.*, joined together in one or two groups); gynœcium, of one carpel (monocarpellary); fruit a legume. The zygomorphic flower, the perigynous condition, the effective pollination mechanism, the single carpel, and the few seeds with their large store of reserve for the seedling plant, are all advanced characters.

Floral formula. K (5) C5 A 5 + 5 G$\underline{1}$. The brackets show that the parts within them are united.

New Zealand Representatives.

1. **The kowhai** is a large shrub with pinnately compound leaves, sometimes growing into a small tree.

The flowers (Fig. 130) are yellow and highly perigynous.

The standard is small,—shorter than the wings; the members of the keel are large and free.

The stamens are all free.

The pod which is constricted at intervals is four-sided and floats in water. This is one of the chief means of distribution of the kowhai.

2. **The Clianthus** (Fig. 130) or scarlet kaka-beak, used to be found near the Maori clearings and is now cultivated in gardens.

The standard is small and reflexed, the wings very small and the keel very large and completely united.

Both Clianthus and Kowhai are pollinated by birds. Look up Pollination.

3. **Carmichaelia**, or New Zealand broom, has no leaves, the twigs being flattened out to form phyllo-clades or cladodes. This and many other things go to show that New Zealand was at one time much drier than it now is. The young seedlings of carmichaelia have leaves. The pods dehisce to let out the seed by the falling away of the side walls from the thickened sutures.

Introduced Plants.

1. The **Sweet Pea** stem has flattened wings that help to do the work of leaves, many of the latter having lost their blades and formed tendrils.

2. In **White Clover** the flowers are arranged in globular heads. Its leaves close at night.

3. **Red Clover** is pollinated by humble bees, the tube leading to the nectar being too long for the tongue of the hive-bee. Till humble bees were introduced this plant rarely seeded in New Zealand.

4. In **Scarlet Runner** the keel is coiled like a watch spring, and contains the similarly coiled stamens and style.

5. **Gorse** has short spine-like branches, and also has the leaves reduced to small spines, though the seedling forms have ordinary foliage leaves. The two back sepal lobes are united to form a large compound sepal, the two side lobes are reduced to small scales and the

front lobe much enlarged. The sepals enclose the mature fruit. The stamens are all united as they also are in the broom, lupin, and laburnum.

Rosaceæ.

The **Brier-Rose** (*Rosa rubiginosa*) (Fig. 131) is a typical plant of this order.

Habit. Shrub six to ten feet high.

Root. Branched tap-root.

Stem. Thorny with curved thorns—much pith.

Leaves. Compound, imparipinnate (*i.e.*, having a terminal leaflet); stipulate, stipules adnate (*i.e.*, united to the petiole); margin serrate; venation reticulate; pinnules oval.

Inflorescence. Definite, solitary.

Flower. Perigynous, actinomorphic, complete.

Calyx. Sepals 5, synsepalous, lifted on the receptacle tube on which are also carried the petals and stamens. The sepal lobes are covered below with oil glands.

Corolla. Petals five, perigynous; apopetalous; petals obovate.

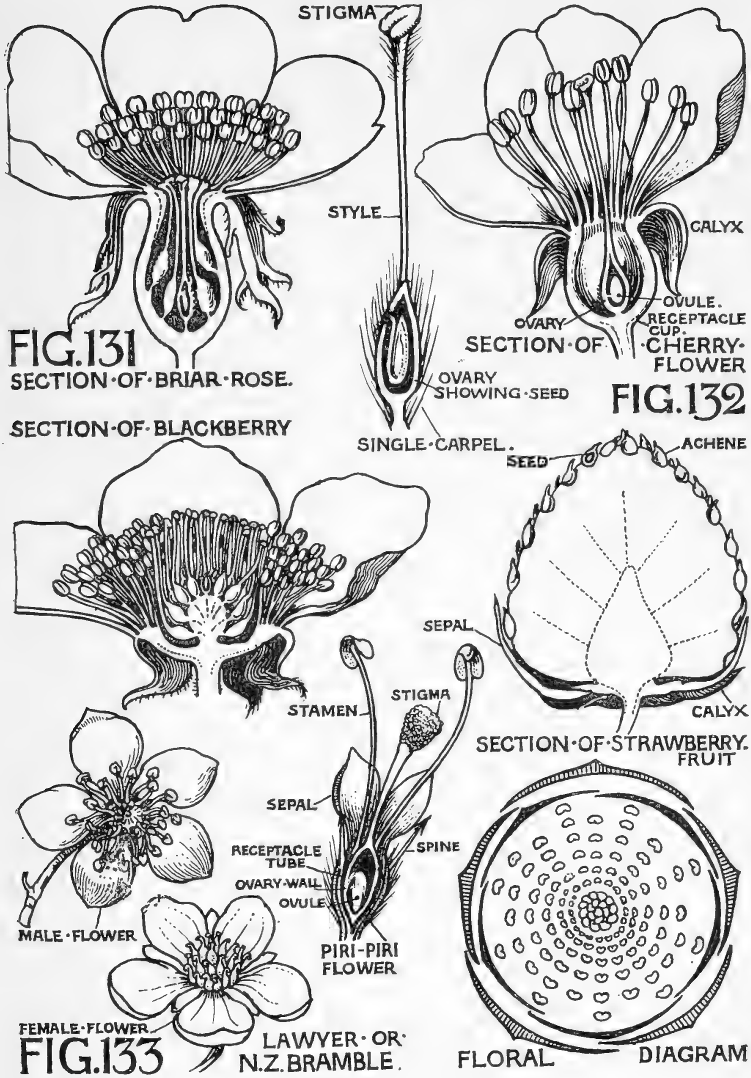
Andrœcium. Stamens ∞ free, perigynous.

Gynœcium. Carpels ∞, apocarpous, fastened to the inside of the cup formed by the raised receptacle tube. Each carpel consists of a terminal stigma brought up to the opening of the calyx cup; long style, and superior ovary containing one ovule.

Fruit. The tube of the receptacle becomes succulent, enclosing the true fruit which consists of numerous achenes. Birds eat the succulent fruit and pass the achenes undigested through their intestines. Thus the plant is spread.

Pollination. The brier produces no nectar, but the flowers are visited by bees for their pollen, the insects being attracted by the showy flower and aromatic

ROSACEAE


STIGMA
STYLE
OVARY SHOWING SEED
SINGLE·CARPEL.
FIG.131
SECTION·OF·BRIAR·ROSE.
CALYX
OVULE.
OVARY
RECEPTACLE CUP.
SECTION·OF· ·CHERRY· FLOWER
FIG.132
SECTION·OF·BLACKBERRY
ACHENE
SEED
SEPAL
CALYX
SECTION·OF·STRAWBERRY. FRUIT
STAMEN
STIGMA
SEPAL
RECEPTACLE TUBE
SPINE
OVARY·WALL
OVULE
PIRI-PIRI FLOWER
MALE·FLOWER
FEMALE·FLOWER
FIG.133
LAWYER·OR· N.Z.BRAMBLE.
FLORAL DIAGRAM

odour of the sepal-lobes. The styles bearing the slightly dilated stigma project a little from the mouth of the flower tube. The stigmas become ripe at the same time as the anthers open, but insects generally alight on the stigmas first and thus bring to them pollen from previously visited flowers.

Characteristics of the order: flowers apopetalous, perigynous, regular; stamens numerous, in whorls; pistil apocarpous. The highly perigynous condition is an advanced character, but the numerous free carpels and stamens show a more primitive condition.

Floral Formula. $K(5), C5\ A\ \infty\ G\ \underline{\infty}$.

New Zealand Examples.

1. **The Lawyer** (*Rubus australis*) (Fig. 133) is practically the same as the blackberry, being a woody scrambler making its way by hooks over and among the vegetation on the edge of the bush. It is, however, diœcious, the male and female flowers being produced on different plants. The fruit is an etario of drupelets as in the blackberry. In this the carpels are not set in a cup but on a dome-shaped receptacle.

2. **The Bidi-bidi** (Fig. 132) properly Piri-piri (*Acæna*) is a creeping plant with much divided leaves.

Inflorescence—a dense globular head.

Flower—has calyx of four lobes, no corolla, two to four stamens, highly perigynous.

Pistil—carpels, one, long style with club-shaped stigma, single ovule. The exserted stamens and large club-shaped stigma go to show that the flower is wind pollinated.

Fruit—an achene distributed by means of barbed hooks formed at the base of the calyx.

This plant is a member of the Rosaceæ because of its highly perigynous nature and the fact that its fruit is an achene.

COMMON EXAMPLES.

1. **Strawberry** (*Fragaria vesca*).

Calyx.—Beneath the calyx is an epicalyx consisting of five members similar to the sepals, and presumably representing the stipules of the latter fused in pairs.

Fruit (Fig. 132).—The succulent part is an enlargement of the receptacle, which swells after fertilization, becoming a fleshy body over which are scattered the little achenes which form the true fruit.

2. **Blackberry** (Fig. 131) **and Raspberry** (*Rubus*).

Fruit.—The carpels enlarge after fertilization and become succulent to form drupelets (little drupes). The fruit is really an etario of drupelets covering the fleshy receptacle. The calyx is persistent as in the strawberry.

3. **Cherry, Plum and Apricot** (Fig. 132) (*Prunus*).

Pistil.—Monocarpous. After pollination the single carpel swells and a one-seeded fruit (a drupe) is produced. The receptacle does not enter into the formation of this.

4. **Apple and Pear** (*Pyrus*).

Pistil.—Consists of five carpels.

Fruit.—After pollination the receptacle tube grows up round the carpels, and becoming succulent, forms a pome, enclosing the five carpels which go to form the core.

5. **Hawthorn** (*Cratægus*).

Pistil.—The pistil differs from that of the apple in consisting of only two carpels.

Fruit.—The inner portion of the receptacle surrounding the carpels becomes hard and forms a stony substance. The fruit has two stones. It is really formed like a pome by upgrowth of the receptacle, as may be seen by the remains of the calyx above; but, instead of a core, it has stones.

Myrtaceæ.

Tea-tree (Fig. 134) or **Manuka** (*Leptospermum scoparium*) is a typical plant of this order.

Habit—rigid, erect shrub, sometimes becoming a small tree; bark in strips.

Leaves—sessile, simple; margin entire; veining pinnate with a marginal vein; apex mucronate (needle-like); pellucid dots showing presence of oil may be seen on holding leaf up to the light and looking at it with a lens.

Inflorescence—solitary at ends of short branches.

Flower—Epigynous (i.e. on top of the ovary), sessile, complete, actinomorphic.

Calyx.—Sepals five, epigynous (*i.e.*, situated on top of the ovary), the five small lobes being deciduous.

Corolla—five, orbicular (*i.e.*, circular) apopetalous, epigynous.

Andrœcium—stamens numerous, free, epigynous arranged just within the petals, incurved in the bud; filaments white; anther two-lobed.

Gynœcium—carpels five; syncarpous; style short and thick with five-lobed capitate (button-shaped); stigma at top. Ovary inferior, five-celled with ovules numerous and very slender; axile placentation.

Fruit.—A woody capsule dehiscing by five slits.

Pollination.—The style usually lifts the stigma above the stamens so that self-pollination is prevented. Insects visiting the flowers bring about cross-pollination.

General Characteristics of the order. Leaves usually opposite, without stipules, entire, leathery, evergreen, aromatic, finely dotted with pellucid glands containing essential oils.

Flowers.—Regular, epigynous; stamens numerous; pistil, carpels joined; fruit usually a berry but in

tea-tree (Manuka) and eucalyptus (Blue-gum) a woody capsule. The inferior ovary of united carpels is the most advanced character of this order. The

MYRTACEAE

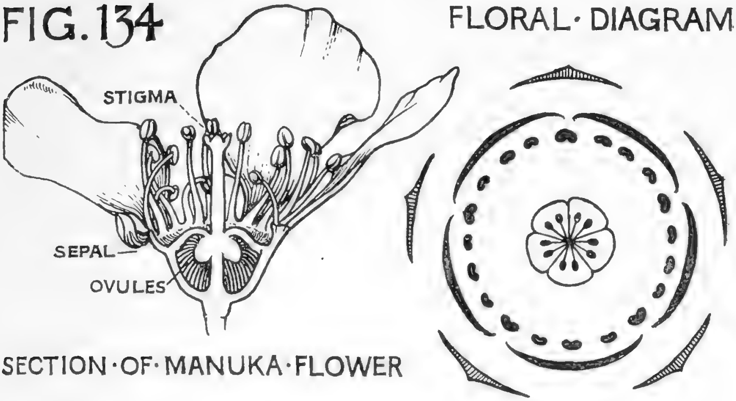


FIG. 134

SECTION·OF·MANUKA·FLOWER

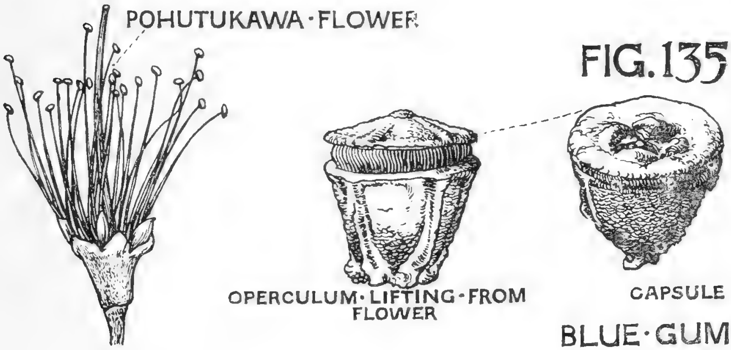


FIG. 135

BLUE·GUM

presence of numerous stamens, however, is a primitive character. The order is chiefly tropical, confined in the main to Australia and America, the myrtle being the only European species.

Floral Formula.—K5 C5 A∞ G $(\bar{5})$.

New Zealand Representatives.

Manuka already described.

Rata and **pohutukawa** (*Metrosideros*), (Fig. 135); various myrtles (*Myrtus*).

In the ratas the numerous stamens are coloured a bright crimson and serve to attract insects.

Introduced Plants.

Blue-Gum (*Eucalyptus globulus*) (Fig. 135), native of Australia.

Habit—large tree with thick leathery bark.

Leaves—both sides the same, hang vertically so that only edge exposed to light, which, in Australia is intense.

Flower—Epigynous, sepal-lobes and petals united to form operculum or lid which falls off when flower opens. Stamens very numerous; carpels usually four, united; ovary four-celled with ovules in axile placentation.

Fruit.—a woody four-celled capsule.

Commercial Products.

Cloves are the flower buds of *eugenia caryophyllata*, a close relative of our *eugenia maire.*

Pimento consists of the unripe dry berries of *myrtus pimenta.*

Guava is the fruit of *psidium guyava.*

Brazil nuts are the seeds from the capsule of *Bertholletia excelsa.*

Bay-rum from *pimenta acris.*

Pomegranate.—Punica granatum.

Eucalyptus yields a valuable oil.

Umbelliferæ.

The Carrot (*Daucus carota*) (Fig. 136) is a good plant to examine. Any of the following, however, will, except for slight differences, answer the same description: parsley, pasnip, fennel, hemlock, celery.

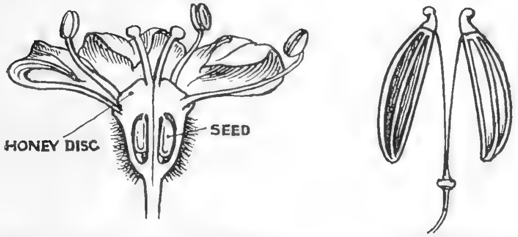
Habit.—A garden vegetable with small white flowers in compound umbels.

Root.—Fleshy tap-root stores food for flowers and fruit in second year, as do many members of this order.

Stem.—Herbaceous, erect, hollow, ribbed, hairy, green.

UMBELLIFERAE

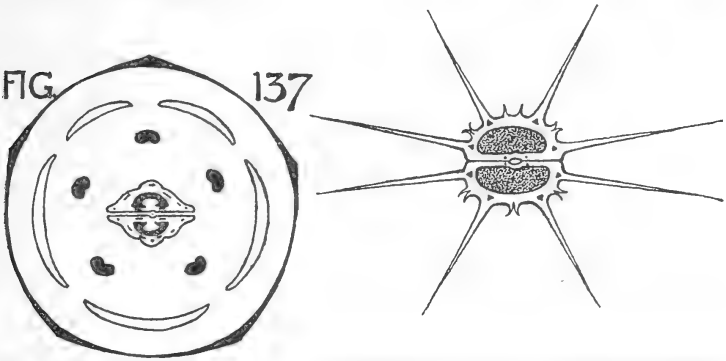
FIG. 136



VERTICAL·SECTION·OF CARROT·FLOWER

CARROT·FRUIT·SPLITTING

FIG. 137



FLORAL·DIAGRAM.

TRANSVERSE·SECTION·OF·FRUIT.

Leaves.—Radical, pinnately compound, with large sheathing bases, exstipulate.

Inflorescence.—A compound umbel, bracts form an involucre at the base of the main umbel with partial involucres (involucels) at the base of all secondary umbels.

Flower.—Bracteate, complete, epigynous, actinomorphic, small. The outer flowers of the umbel are often more or less zygomorphic.

Calyx.—Synsepalous, five-lobed, superior, green and hairy. In many of the plants of this order the calyx lobes are so reduced that the five minute teeth are almost indistinguishable.

Corolla.—Petals five, apopetalous, epigynous, white; petals often incurved, alternating with sepals.

Andrœcium.—Stamens five, free, epigynous, alternating with the petals.

Gynœcium.—Carpels two, syncarpous; two short styles surmount a large disc (nectary) and at the ends of these are the stigmas; ovary two-chambered, inferior, with a single suspended ovule in each cell.

Fruit.—A schizocarp splitting into two mericarps. After division, the two nut-like mericarps are held together by the carpophore, which is really a continuation of the flower-stalk. Each mericarp has five more or less projecting ridges. Inside the grooves between the ridges, oil-ducts (vittæ) are found. The seed has a little endosperm which does not contain starch, but oil.

Pollination.—The flowers are markedly protandrous (*i.e.*, the stamens ripen before the stigma), and the epigynous honey-disc being easily accessible, are visited by many short tongued insects especially flies and beetles.

Seed Dispersal.—The fruits of this order are distributed by the wind, or, being rough, may cling to the coats of animals. In fennel, the fruits are not flat, but as the stem remains right through the winter the strong blasts blow the fruit away.

Characteristics of the Order.—In all essentials the plants of this order closely follow the carrot and the others mentioned. Many species, *e.g.* Hemlock, are

poisonous. The epigynous condition, the protandrous flower, the form of inflorescence and the reduction of the ovules to one in each cell are all advanced characteristics.

Floral Formula.—K(5) C5 A5 G $(\bar{2})$.

NEW ZEALAND EXAMPLES.

1. **Hydrocotyle.**—A small creeping herb with simple rounded leaves and flowers in simple umbels of a very few flowers; has a considerable number of species in New Zealand.

2. **Creeping celery** (*apium prostratum*) is found plentifully in many places on the sea coast, and may easily be recognised by its smell.

3. **Spear-grass** (*Aciphylla*) is, however, the most striking of the New Zealand umbelliferæ. There are several native species in all of which the leaves are pinnately divided, the leaflets in most cases being spiny.

The umbels are not flat-topped, as is usually the case in this order, but are massed in compact panicles.

The flowers are generally diœcious.

COMMON UMBELLIFERS.

1. **Parsnip** (*Pastinaca sativa*) cultivated for its fleshy tap-root.

2. **Celery** (*Apium graveolens*) cultivated for the fleshy petioles.

3. **Parsley** (*Carum petroselinum*) cultivated for its leaves, which are used as garnishing and dressings.

4. **Carrot** (*Daucus carota*) for fleshy tap-root.

5. **Caraway** (*Carum carui*) used for its fruits.

6. **Hemlock** (*Conium maculatum*), now well established as a weed in many places in the neighbourhood of Auckland, is a glabrous herb with hollow stems often reaching a height of three feet. The lower portion of the stem is often spotted with purple. If

the plant is brushed, it emits an unpleasant odour which resembles mice. Hemlock was the state poison of Athens, and by it Socrates met his death.

Compositæ.

The plants of this order are divided into two sub-orders.

(*a*) **Tubulifloræ**—with disc florets only or with ray and disc florets, *e.g.* daisy, matricaria.

(*b*) **Ligulifloræ**—with no disc florets, all the the flowers being ligulate or strap-shaped.

The **Field daisy** (*Bellis perennis*) (Fig. 138) is a well-known member of the Tubulifloræ.

Habit.—A perennial herbaceous plant, growing in meadows.

Stem.—A rootstock (a short rhizome) giving off leaves above and roots below.

Leaves.—Radical, petiolate, spatulate (*i.e.*, spoon shaped), toothed, green.

Inflorescence.—A head or capitulum (*i.e.*, the flowers are massed together on a common receptacle and are sessile).

Flowers.—The central flowers are the disc florets and those on the outside the ray florets. The disc florets are tubular and have present all parts but the calyx. These flowers are actinomorphic and epigynous. The ray florets have neither stamens nor sepals, and are strap-shaped, not tubular, the petals being united to form a flat blade. They are zygomorphic and epigynous.

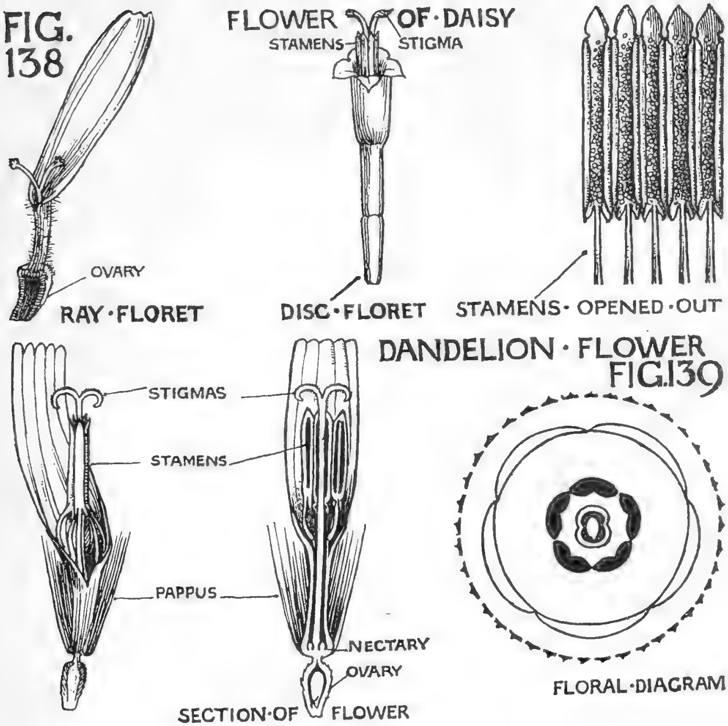
Calyx.—Not distinguishable in either disc or ray florets.

Corolla.—Petals five. Disc florets tubular with five lobes, synpetalous, epigynous; ray florets, petals united to form a strap-shaped body, synpetalous, epigynous.

Andrœcium.—Stamens absent from ray florets. In disc florets stamens five, syngenesious (*i.e.* joined by

their anthers), epipetalous. The five anthers unite to form a tube enclosing the style. Into this tube the pollen is shed.

COMPOSITAE



Gynœcium.—Carpels two in both ray and disc florets; syncarpous; stigma two-lobed; ovary inferior, one-celled containing a single ovule.

Fruit.—A cypsela, *i.e.*, a fruit after the nature of an achene but formed from an inferior ovary derived from two united carpels.

Pollination.—The disc flowers are protandrous. The pollen from the stamens is shed into the tube up which the style pushes its way. This style brushes out the pollen, and, when it emerges from the tube, splits, scattering the pollen on both sides and exposing the stigmatic surfaces on the inner side of the split. None of this pollen reaches these surfaces, and, as a rule, the flower is pollinated by pollen brought by insects from other flowers. If, however, cross-pollination does not take place, the two halves of the split style curl round and touch the pollen on the exterior surface of the style lower down, thus effecting self-pollination.

The **Dandelion** (*Taraxacum densleonis*) (Fig. 139), is a typical member of the Liguliforæ.

The description of the dandelion flower answers that of the ray floret of the daisy with the following additions:—

1. *Calyx* present as a pappus of hairs arising in five tufts.

2. *Andrœcium*—stamens five, syngenesious, epipetalous.

3. *Distribution* of fruit by wind with the help of a pappus of hairs derived from the five calyx lobes.

In habit the dandelion is a perennial herb which exudes a milky fluid when cut or broken. The leaves form a rosette.

The **characteristics** of the composite order are remarkably constant throughout a wide range of species. About 10 per cent of the plants of the globe belong to this order, which is generally considered as the head of the Vegetable Kingdom. As we have seen, it is specially adapted to survive in the struggle for existence in almost any surroundings. The massing of the flowers in heads, the epigynous condition, the reduction of the ovary to a one-celled body with a single ovule, the protandrous flower, with its simple

but effective pollination mechanism, and the numerous devices for distribution of the seed are all advanced characters.

Floral Formula.—K(5) C (5) A(5) G$(\overline{2})$.

Commercial Products.

1. **Sunflower** (*Helianthus annuus*) is cultivated for its seeds, which yield a valuable oil.

2. **Jerusalem artichoke** (*Helianthus tuberosus*) cultivated for its tubers.

3. **Chicory** (*Cichorium intybus*) used for its roots which are dried in kilns, roasted, ground, and mixed with coffee.

4. **Lettuce** (*Lactuca*), used for salad.

5. **Dandelion**—medicinal.

New Zealand Examples.

New Zealand is rich in a considerable variety of plants belonging to the compositæ. Whereas the species of this order which belong to the British flora, are herbs, New Zealand examples comprise herbs, shrubs, and trees.

1. **The haastias** and **raoulias** are remarkable cushion plants found in stony river-beds and on rocky mountain sides. They shade the ground even more effectively than rosette-plants, their low-growing, rounded form renders them practically immune from the storms that sweep the mountains, while the dense hairs with which their exposed parts are felted doubtless serve to guard against extremes of heat and cold, and to check undue loss of water by transpiration.

2. The **rangiora** is a small tree which bears large undivided leaves and much branched panicles of small inflorescences. The under sides of the leaf blades are covered with fine white down (*tomentum*) which gives the leaf its characteristic appearance when waving in the breeze. The rangiora is one of

the first trees to appear after the bush has been burned off.

3. **The olearias** are shrubs and trees.

4. **The celmisias** are daisy-like flowers with tough usually lanceolate leaves found chiefly in alpine districts.

L. Cockayne, Ph.D., F.R.S., photo

Vegetable Sheep *(Raoulia eximia)*, Mt. Torlesse, Canterbury; sub-alpine belt.

5. **The senecios** are chiefly shrubs. They are nearly related to the common groundsel.

MONOCOTYLEDONS.

Speaking generally, monocotyledons differ from dicotyledons in having parallel veined leaves, scattered vascular bundles without cambium, only one cotyledon in the seed, and the parts of the flower in threes instead of fours and fives, as is usually the case in dicotyledons. These distinctions, however, do not

all hold good in every case, for the supple-jack which is a monocotyledon, has net veined leaves, while the dock and sorrel which are dicotyledons, have their parts in threes.

Among monocotyledons, only the grass and lily families are prescribed for study. It is generally easy to distinguish a grass, the only fear being that it may be confused with a sedge. By examining the culm or flowering stem, however, the student may make practically certain, for in a sedge, it is solid, while in a grass it is usually hollow. Among grasses, however, maize and a few others have solid culms.

To distinguish the common types of monocotyledonous flowers in which the parts are arranged in threes, the following key will be useful:—

1. **Liliaceæ** (Lily order) superior ovary.

2. **Iridaceæ** (Iris order), inferior ovary, three stamens.

3. **Amaryllidaceæ** (daffodil order), inferior ovary, six stamens.

LILIACEÆ.

The Hyacinth (Fig. 140) is a typical flower of this order, but, with very slight variation, the same description would fit the Christmas Lily, onion and other alliums, supplejack or cabbage tree.

Habit.—A perennial herb with an underground bulb, narrow radical leaves, and a raceme of sweet-smelling blue flowers.

Root.—Adventitious roots are given off from the lower surface of the bulb.

Stem.—An underground tunicated bulb.

Leaves.—Radical, simple, narrow, entire, green; form fleshy sheaths below ground, investing the stem.

Inflorescence.—Indefinite; raceme, with two blue bracts at base of each pedicel.

Flower. — Bracteate, complete, actinomorphic, hypogynous.

Perianth.—Synphyllous (united at base only); six lobes in two whorls of three, inferior.

N.B.—When the members of the perianth are all petaloid or all sepaloid no distinction is made between sepals and petals. The ending **phyllous** (Gk. *phyllon*, a leaf) refers to the whole perianth.

LILIACEAE

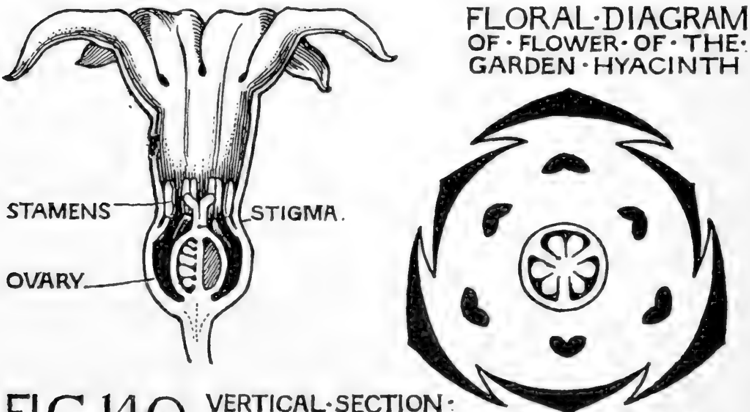


FIG. 140 VERTICAL·SECTION·OF·FLOWER·OF·GARDEN·HYACINTH.

Andrœcium.—Stamens six in two whorls; epiphyllous, free; anther two-lobed, versatile (*i.e.*, capable of turning on the filament); filament blue.

Gynœcium.—Carpels three, syncarpous; style long; stigma three-lobed; ovary superior, three-celled with numerous ovules in axile placentation.

Fruit.—A capsule dehiscing by three valves; seeds have endosperm.

Pollination.—Usually by insects, but as stamens and stigma ripen at the same time, self-pollination may take place.

It is the superior three-chambered ovary that distinguishes this order from other monocotyledons.

Floral Formula.—P 3 + 3 A 3 + 3 G ($\underline{3}$).

NEW ZEALAND EXAMPLES.

1. **Flax** (*Phormium tenax*).—*Stem*, a fleshy rhizome. *Leaves*—large, ensiform (sword-shaped) with parallel veins. *Inflorescence*—a very large scape, each flower cluster being protected by a spathe. *Perianth* six, free, hypogynous in two whorls, reddish brown, somewhat irregular. *Stamens* and carpels as in blue-bell. *Fruit*—an elongated three-angled capsule showing many shining black flat densely-packed seeds. *Pollination* by birds. In getting the nectar, tuis and other birds get the pollen on the feathers at the base of the beak and thus carry it from one flower to another. *Use.*—The fibres of the leaf are taken out and used for most purposes for which hemp can be used.

2. **Supplejack** (*Rhipogonum scandens*).—A woody, branching forest climber. *Leaves* ovate, glossy net-veined with entire margin. *Inflorescence*—a raceme sometimes a panicle. *Flower*, regular, with all the characters of the order, but very small and greenish. Each chamber of the ovary contains only one ovule. As the ovary matures, one or more of the ovules is absorbed and the fruit becomes a one-seeded berry. It is scarlet in colour.

3. **Cabbage tree** (*Cordyline*) has a palm-like habit with a straight leafless trunk bearing at its summit a tuft of sword-shaped leaves. The flowers, which are small and white, are produced in large panicles. The fruit is a bluish white three-celled berry with one to three black angular seeds in each chamber.

4. **The Astelias** are mostly epiphytes and rock plants. The bases of the sword-like leaves sheathe one another and thus form a receptacle for the storage of water, a matter of importance to a plant which cannot as

a rule draw its supplies from the ground. The flowers which are diœcious are produced in large panicles. In *Cunningham's astelia* and *Astelia linearis* there is a distinct departure from the true lily type in the fact that the carpellary leaves have not folded in but have merely united by their edges, so that the ovary is one-celled and the ovules, instead of being in axile placentation, are on three parietal placentæ.

Introduced Liliaceous Plants.—Yucca, tulip (stigma sessile), hyacinth, onion and various lilies.

GRAMINACEÆ.

Prairie Grass, the Brome (*Bromus unioloides*) (Fig. 141).

Habit.—Herbaceous, with upright sheathing leaves.

Root.—Fibrous, adventitious.

Leaf.—Linear, parallel veined, sheathing; sheath split in front; the *ligule* is a scaly appendage on the leaf just where it passes into the sheath.

Stem.—Hollow, except at the nodes.

Inflorescence.—A panicle of spikelets.

Spikelet.—Consists of a slender axis bearing a number of scales in two rows. The two bottom scales, one on each side, are the barren or empty glumes. The other scales are bracts with flowers in their axils. These are called the outer pales or flowering glumes. The axis of the flower bears a scaly bracteole called the upper or inner pale. It is opposite the bract.

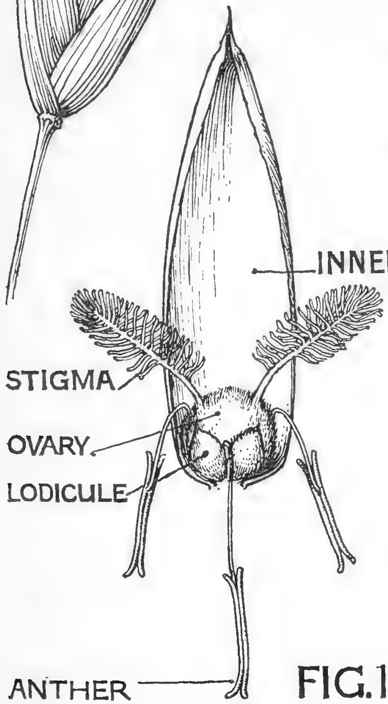
The flower lies between the outer and inner pale.

Lodicules.—Two small scales at the base and in front of the ovary representing either a single scale or two lobes of a suppressed perianth. These swell and thus separate the pales to free the anthers and styles.

Andrœcium.—Stamens three, free, hypogynous, one in front between the lodicules, and one at each side behind the lodicules. Filament long, slender, hanging out of flower; anthers large, versatile.

GRAMINACEAE

FIG. 141



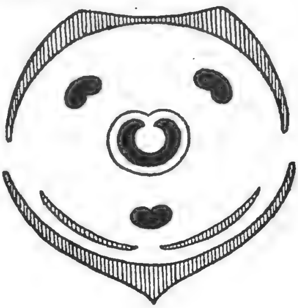


FIG. 142

Gynœcium.—Carpel one, bearing two feathery stigmas; ovary one-chambered, superior, containing one ovule.

Fruit.—A caryopsis; seed contains endosperm. Seed coat and seed case (ovary wall) are fused together.

Pollination—by wind for which the exserted stamens and abundance of light pollen and feathery stigmas are well suited.

The **characteristics** of this order even to the presence of the ligule are very constant throughout the whole world.

Floral Formula.—P $0 + 2$ A $3 + 0$ G $\underline{1}$.

This is intended to show that the grass is of the ordinary monocotyledonous type. The outer whorl of the perianth is missing. In the inner whorl the back lobe has been suppressed. It is the outer whorl of stamens that is complete, as is shown by the fact that the front stamen is opposite the gap between the two lodicules. The inner whorl of stamens is missing and the carpels are reduced to one.

New Zealand Examples.

1. **Arundo conspicua** (*Toetoe*) is a tall grass forming clumps in swamps and damp places generally. The leaves are long and have a hard cutting edge due to the presence of silica. The inflorescence is a dense panicle much like that of pampas grass, but smaller and drooping.

2. The **danthonias** are capital pasture grasses for poor clay lands. They are nutritious and much relished by stock.

3. The **poas**, native representatives of the European meadow-bent grass, form much of the tussock land.

Introduced Grasses,

1. The **bamboo** reproduces chiefly by rhizomes, and so successful is this method that its seed matures only once in about twenty years.

2. The **maize** is monœcious, the cob bearing the pistillate, and the tassel above the staminate flowers. The long silky hairs on the cob are the stigmas. Maize does best when fertilized by pollen from another plant.

3. **Wheat, oats, barley** and **rye** are common **cereals** used for human food.

4. **Rye grass, cocksfoot, timothy, crested dogstail,** and **meadow foxtail** are well-known pasture grasses.

COMMON FLOWERS.

In order that the student may have plenty of practice in plant description the following selection is made. Brief notes are given with respect to every flower, but should be used by the student only for the purpose of verifying and correcting the results of his own observations.

The Rush.—P 3 + 3 A 3 + 3. Carpels three; ovary three-celled, axile placentation, superior.

The Narcissus.—P (3 + 3) A 3 + 3 epiphyllous; carpels (3); ovary three-celled, inferior; axile placentation. The corona or cup is an outgrowth of the perianth.

The Snowdrop.—As above, but members of perianth free and no corona.

Iris.—As narcissus except that only three stamens. Petaloid styles and pollination mechanism already described. Freesia, Gladiolus, Ixia, Crocus—as iris but without pollination mechanism.

Canna.—K 3 C3. Andrœcium represented by a number of petaloid bodies of which only one, the posterior stamen of the inner whorl bears a two-lobed anther; of the staminodes one is larger than the others and reflexed forming the labellum G $(\overline{3})$.

Dock.—P (3 + 3) A 3 × 2. Carpels (three) united to form a superior one-celled ovary containing one ovule. Fruit a nutlet.

Chickweed.—K 5 (inferior) C 5 (hypogynous), A 5 free, hypogynous, ovary one-celled, free central placentation.

Barberry.—K 3 + 3 (inferior) C 3 + 3 (hypogynous) A 3 + 3 (hypogynous) G ($\underline{1}$).

Poppy.—K 2 (inferior, deciduous) C 2 + 2 hypogynous; stamens numerous, hypogynous; carpels numerous, united to form a superior one-celled ovary with numerous ovules in parietal placentation.

Mignonette.—Flowers hypogynous, K 6 C 6 (fringed) A ∞ G ($\underline{3}$), parietal placentation.

Escholtzia.—Similar to poppy but perigynous.

Fumitory.—A delicate soft-stemmed weed with small pink irregular flowers. K 2 (inferior), C 2 + 2 (hypogynous). A 2 + 2. Ovary one-celled with one ovule.

Pansy.—K 5 (inferior), C 5 (hypogynous), A 5 (hypogynous), G($\underline{3}$). Ovary one-celled, parietal placentation. Pollination mechanism described.

Geranium.—K 5 (inferior); C 5 (hypogynous), A 5 + 5 (hypogynous); outer whorl opposite not alternate with petals; G ($\underline{5}$); ovary five-celled; axile placentation; fruit a schizocarp.

Tropæolum.—Flower zygomorphic; receptacle under posterior sepal prolonged into a spur. K 5 (inferior) more or less coloured. C 5, two back petals perigynous, three front hypogynous. Stamens eight in two whorls, middle stamen of each whorl having been suppressed. G ($\underline{3}$), ovary three-celled, one ovule in each. Fruit a schizocarp splitting into three drupe-like fruitlets.

Mallow.—K 5 (inferior, united), also epicalyx, C 5 (hypogynous) twisted in the bud with bases slightly united. Stamens five, each broken up into many members forming a bunch. The five stamens are united at the base to form a tube joined to the base of the petals. Carpels numerous; ovary superior, many-celled. Fruit a schizocarp splitting into about eight fruitlets.

Daphne.—K (4), C absent; A (4 + 4), perigynous $G\underline{1}$. Ovary, superior, one-celled, one ovule.

Pumpkin.—Plant monœcious; flower epigynous; K (5), C (5), A (5) united to form a tube, G $(\overline{3})$; ovary three-celled. Fruit a berry.

Fuchsia.—Flower epigynous; calyx four-lobed, petaloid; C 4, A 4 + 4 G $(\overline{4})$; ovary four-celled. Fruit a berry.

Heath.—Flower hypogynous. K 4 C 4 A 4 + 4 G $(\underline{4})$. Ovary four-celled.

Primrose.—Flower hypogynous K (5), C (5), stamens 5, epipetalous, G $(\underline{5})$ united to form a one-celled ovary; free central placentation. Pollination mechanism described.

Convolvulus.—Flower hypogynous K (5) C (5) A (5), epipetalous, G $(\underline{2})$; ovary two-celled.

Nightshade and **Potato-flower.**—Hypogynous K (5) C (5) A (5) epipetalous, G $(\underline{2})$; ovary two-celled, set obliquely. Fruit a berry.

Snapdragon and **Foxglove.**—Flower hypogynous K (5) C (5) A 4, epipetalous, two long and two short; back stamen suppressed G $(\underline{2})$. Ovary two-celled; numerous ovules on two axile placentæ. Fruit a capsule.

Veronica.—Flower hypogynous K (4) C (4) A 2, epipetalous G $(\underline{2})$; ovary two-celled. Fruit a capsule.

Plantain.—Flower hypogynous K (4) C (4) A 4 epipetalous G $(\underline{2})$; ovary two-celled.

Salvia.—K (5), C (5). Only two front stamens developed, but rudiments of the two side stamens present. G $(\underline{2})$ divided into four cells by a false septum. Fruit four nutlets. Pollination mechanism described.

Periwinkle.—Flower hypogynous, K (5) C (5) A 5, epipetalous $G\underline{2}$. The two carpels alternate with the two nectaries. Fruit two follicles.

Coprosma.—Plant diœcious; flower epigynous K (4 – 5), C (4 – 5) A 4 – 5 epipetalous, exserted G $(\bar{2})$; ovary two-celled, one ovule in each cell. Fruit a drupe.

Honeysuckle.—Flower epigynous K (5), C (5) A 5 epipetalous; G $(\bar{3})$ ovary three-celled axile placentation.

Campanula.—Flower epigynous K (5) C (5) A (5) epipetalous; G $(\bar{3})$; ovary three-celled with numerous ovules in axile placentation. Fruit a capsule.

QUESTIONS ON CHAPTER VIII.

1. Describe and compare the leaves, flowers, and fruit of the buttercup, columbine, larkspur, and clematis.
2. Compare the flower of the buttercup with that of the wallflower, taking first the general structure and then each whorl separately.
3. Compare the gynoecia of the lily, wallflower, pea, and rose.
4. Compare the white clover with the pea.
5. Compare the gynoecia and fruits of the cherry, raspberry, strawberry, apple, hawthorn, rose.
6. How do the following attract insects:—Pea, lily, iris, rose, daisy? What benefits do the insects confer on the flower, and how are the insects paid?
7. What benefit has been conferred by the introduction of the humble bee into New Zealand?
8. What insects have you seen visiting the manuka? How have they been attracted?
9. In parallel columns describe one native and one introduced plant belonging to the leguminosæ. Note carefully the points of likeness and difference.
10. To what orders do the following belong:—Cabbage tree, cabbage, parsnip, plum, tulip, freesia, snowflake, daffodil, clover, piri-piri, danthonia?
11. Explain how a grass flower may be referred to the ordinary monocotylous type.
12. How would you distinguish the lily, iris, and amaryllis families?
13. To what orders studied by you do the plants most useful to man belong? Enumerate and classify these plants.
14. Distinguish between species, genus, and natural order, and give three examples of each.
15. Show clearly how the blackberry, rose, plum, and piripiri all conform to the same type.

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